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Improving the PH-1110/1111/1120/1121 Physics Laboratories

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INTERACTIVE QUALIFYING PROJECT

Improving the PH-1110/1111/1120/1121 Physics Laboratories

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Abstract:

In an effort to improve the quality of learning at Worcester Polytechnic Institute, this paper includes an in depth analysis of each of the laboratories in PH-1110, PH-1111, PH-1120, and PH-1121. More specifically, the authors have identified room for improvement in the following areas:

- Grading Guidelines
- Software used in labs
- TA training
- Lab time management
- Board diagrams
- Instruction clarity
- Laboratory equipment
- Excessive TA intervention

Executive Summary

Laboratory classes provide students with a unique opportunity to put the knowledge and skills that they have obtained during lecture to practice. Ideally, laboratory experience should not only reinforce students' understanding of the material, but also allow teach students how to effectively create an experiment, collect data, and analyze the results of the experiment. Between September 2014 and March 2015, we evaluated the laboratory components of both the Mechanics and Electricity and Magnetism physics courses that are offered at WPI. Through careful analysis of each experiment, we have uncovered substantial deficiencies in the physics laboratories that can be readily fixed.

First, the lab instructions provide students with an explicit set of steps to follow in order to reach a provided conclusion. In a real laboratory setting, scientists are not given the answers in advance. Instead, they must design an experiment to test a hypothesis and then analyze the obtained data in an effort to reach a conclusion.

There are also issues with the way that students are assessed in the laboratory. The grading rubrics that are given to teaching assistants are ineffective at measuring the students' understanding of the physics and are too vague to apply consistently and fairly between sections. The use of a single, broad rubric should be avoided because no two experiments are the same. Instead, the teaching assistants should be given a set of standards that is individualized for each laboratory. In doing so, TAs will be able to grade more consistently across sections, and in turn, the grades will much more accurately reflect the students understanding of the physics.

Next, the lack of formalized training makes it difficult for teaching assistants to provide students with an appropriate and consistent level of support. In a survey that we conducted as a part of our evaluation, 80% of respondents felt that current TA training was insufficient. There should be a formalized training session put in place before each term to better familiarize teaching assistants with each lab. This will not only allow TAs to better assist students throughout the laboratories, but also teach the TAs how to provide students with assistance without intervening in excess.

We also identified problems with laboratory equipment – such as defunct power supplies, unresponsive sensors, and sluggish computers. In many cases, equipment failure prevented students from collecting useful data. In order to resolve this issue, TAs should be trained on how to diagnose problems with both the computers and equipment. Furthermore, equipment should be thoroughly tested at the beginning of each term to ensure that everything is working properly.

Finally, the software and spreadsheets that are given to students in order to help them complete the experiment remove the need to truly understand the underlying physics. In many experiments, students are told to enter data into a spreadsheet or use a specific set of functions in Logger Pro to help reach a result. While these tools are helpful for analyzing data, many students use the software without having a strong understanding of what they are doing. Instead, students should be comfortable with analyzing data by hand before being provided tools that help facilitate data analysis. Furthermore, students should not be given preformatted spreadsheets with which they can input data into. If a student wishes to use a computer to expedite their analysis, they should be the one to create it – after all, it is their experiment.

Fortunately, using the findings from our report, Professor George Phillies has already begun incorporating many of these changes into the PH-1111 laboratories and is greatly improving the educational value of the Physics Laboratories at WPI. We hope that our findings will help the physics department continue to improve and better prepare students for their careers upon graduation.

Contents

Introduction

Our interactive qualifying project serves to identify and analyze areas for improvement in the PH-1110, PH-1111, PH-1120, and PH-1121 laboratory curriculum. We believe that improvement is a continuous process -- and we have worked hard to identify places in which the physics laboratories may be enhanced. In our report, we have identified several key areas in which there is room for improvement and have thoroughly documented the suggestions in the chapters below. In the subsequent chapters, we will discuss each laboratory in depth and mention any areas in which the experiment can be improved. Afterwards, we will include the results of our survey, in which the teaching advisors have provided input about the physics laboratories at WPI and noted any problems that they have encountered while teaching the experiments. In the appendix of our report, we have included the procedures and worksheets for each experiment and once more attached our analyses for the reader's convenience.

Grading Guidelines:

The implementation of a grading rubric is extremely important in ensuring that lab reports are graded in a fair and impartial manner. While it is important that the TAs have a clear understanding of the grading process, it is equally important that students are familiar with the evaluation process as well. Otherwise, it is extraordinarily difficult for students to meet the expectations of the graders. At the time of writing, all lab information is available at the following location:

http://users.wpi.edu/~physics/Labs/index.html

In the center of the page, there is a link that is marked, "Grading Guidelines for PH-1110". However, there is no such link for PH-1111, PH-1120 or PH-1121. Ideally, there should be separate, clearly labeled grading guidelines for each of the physics courses. Implementing rubrics for each class will make it easier for students to hand in higher-quality work, and enable TAs to grade more uniformly.

At the top of this rubric is the sub header, "Full score is 10 points fpr [sic] PH-1120. For PH-1121, you will be graded out of 10 points". Because students are brought to this page with the expectation that they will be reading a rubric for PH-1110, it is unnecessary to include this statement unless the rubric is intended to be used across all physics labs. This statement also raises questions about the point totals listed in the rubric. When labs are returned to students, students are typically given a score out of fifty points instead of the ten that is indicated on this page. In order to improve the readability of this rubric, the rubric and the scores should be adjusted to agree with each other. Doing so will not only make the rubric easier to understand, but also make the grading process easier for TAs.

One of the most evident problems with the grading rubric is that it does very little to measure the student's understanding of the main ideas of each lab. This problem was also identified by TAs in the anonymous feedback survey that was conducted for the purpose of this report. One

TA commented, “The grading guidelines generally penalize simple mistakes the most (proper format, sig figs, etc) but do not verify whether the student grasped the physical concept or put forth any effort toward understanding the purpose of the lab”. Furthermore, because the grading rubric is so vague about deductions, it is difficult for TAs to grade consistently. There are a few ways to improve the uniformity of the grading process. First, by providing both students and graders with a sample of a high quality lab report at the beginning of the term, graders would have a standard from which to measure submissions against -- and students would have a better understanding of what type of work is expected. In the survey that was conducted, one TA noted, “I think the grading process would improve a great deal if answer sheets and point values were given to TAs. That way grading is consistent and objective. Since each lab is different, it's difficult to have one single set of clear, concise instructions. I think the ones we have are too general to give the students a good understanding of our expectations”.

Grading guidelines for lab worksheets

Full score is 10 points fpr PH-1120. For PH-1121 you will be graded out of 10 points.

Points	Reason
-10	Identical worksheets turned in by both partners
	Unexcused absence
-5	No names
	Submission by email or paper
-2	For each day late, per business day. The markdowns start from the assigned due date, not from the day you do the lab. Remember all Labs must be submitted
	Missing or incorrect section numbers
-2	Names in improper order
	Incorrect submission via myWPI
-2	When no example given for a calculation
	Improperly labeled figures
-2	Incorrect concept
	Incorrect units
	Calculation error
-1	Neglected units, up to five points
	Unacceptably large uncertainties, fractional changes, etc.

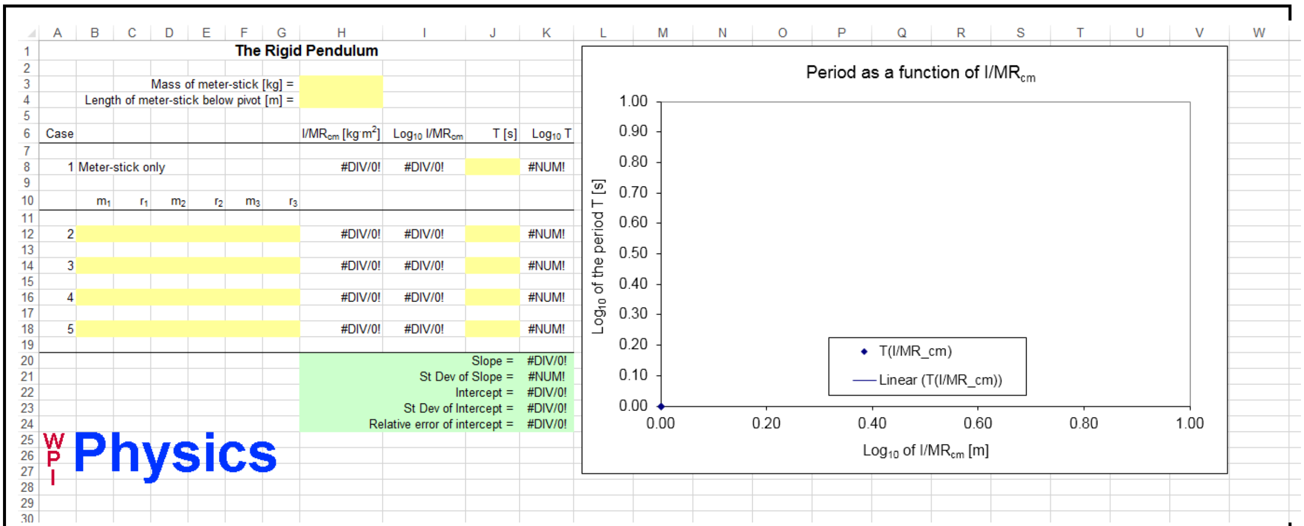
All lab worksheets must be submitted before noon on the last Monday of the term.

Software:

The physics department does an excellent job exposing students to a variety of different technologies within the lab. Each lab computer is equipped with Logger Pro software and the complete Microsoft Office suite. In most labs, students are required to use these programs in order to collect, arrange, and analyze data. While providing students with access to these tools can be extraordinarily helpful when working with complex sets of data, it is crucial that students are also taught to analyze and perform calculations on data by hand. In many labs, the instructions tell students to use the built in functionality within Logger Pro to analyze data, but are not explicit in explaining what exactly the software is doing.

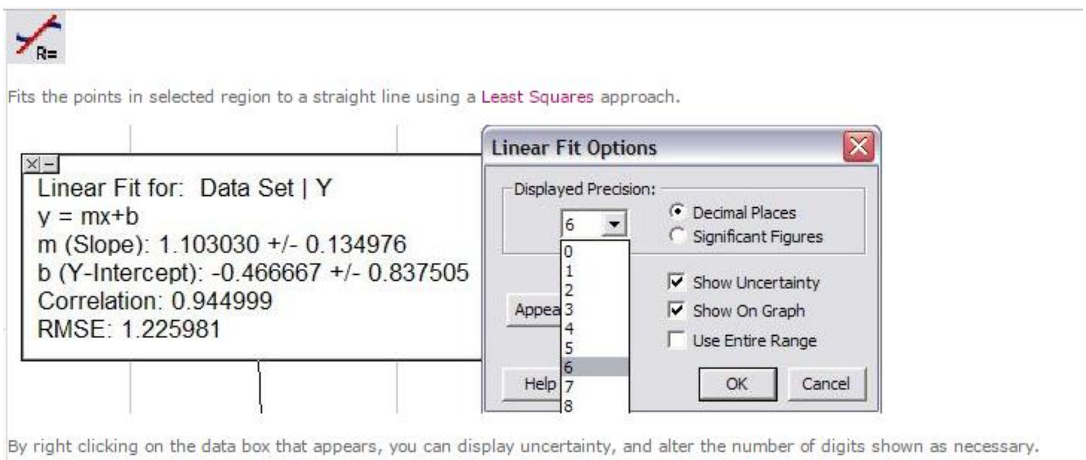
This problem is most evident in the way that students are taught to perform regression analysis on their measurements. In Lab 0, students are told to make measurements, and then are taught how to perform a least-squares fit on paper. This is excellent practice for students. However, in all subsequent labs, students are simply told to use Logger Pro's built in line-fitting tools and the calculations are never done by hand again. While it is certainly useful for students to have access to these tools, knowing how to properly fit data is an invaluable skill and encouraging students to build a dependency on the software should be avoided.

In addition, many lab procedures come with data spreadsheets included. While some of these spreadsheets are merely tables in which students may record their data, some of the spreadsheets perform a calculations on student data as soon as the measurements are entered. While including formulas within the spreadsheet helps students complete the experiment in a timely manner, very few students will take the time to learn from and understand computations that are pre-computed.



The spreadsheet in PH-1111's Lab 9 includes a multitude of statistics and a graph that will automatically fill when data is provided.

Next, both students and TAs experienced considerable difficulty using the Logger Pro software. Nearly all students -- and even some TAs -- have had very little experience using Logger Pro. The lab procedures generally attempt to alleviate this problem by including links that direct users to a brief description of how to complete a specific operation. However, the instructions are often too generalized to be helpful.



This is the page that students are brought to when clicking the "least squares fit" link that is included in PH-1111's Lab 3.

Instead, it would be immensely useful to provide students with the software manual so that students and TAs can better diagnose and solve questions or issues that may arise during lab. An excellent reference guide can be found here:

http://www2.vernier.com/manuals/LP3QuickRefManual.pdf

Finally, in order to improve the TA's ability to diagnose problems with the sensors, it is important that both students and TAs be familiarized with the Vernier equipment manuals as well. These can be found at the following location:

http://www.vernier.com/support/manuals/

TA Training:

It is important for the TAs to be adequately trained to run their lab section, but many of the TA's think that they are not given the proper training. The TAs need to be familiar with the lab instructions, lab software (specifically Logger Pro), troubleshooting with MyWPI and Logger Pro, lab equipment, and the topics being covered in each lecture. The TAs should begin every term with confidence in all of the listed areas. Training the TAs is what should give them that confidence so that they can run a successful lab section.

The training currently in place did a good job of preparing the PH-1110 TAs for their sections. For instance, one term before the labs had started all the PH-1110 TAs and the lab instructor Mr. Hutson met to review every lab for the term. Each TA was assigned a lab to review and then present to the rest of the group, so that all the TAs could discuss the lab together and answer each other's questions. This meeting exposed the TAs to every lab, specifically every set of lab instructions was thoroughly covered. Another effective training technique is the lead TA and assistant TA format. Each lab is taught by a lead TA, who is usually a more experienced, and an assistant TA, who is usually less experienced. The assistant TA can learn while working with a lead TA, like having a new employee shadow a veteran. The assistant is helping students with their questions too. The point of training TAs is to make them feel more comfortable in their lab section. The PH-1110 review session and the assistant TA format do a good job of clearing up confusion that the TAs might have, which ensures that they can run a successful lab.

While some the techniques in place to train TAs are successful, there are ways that training can be improved. The aforementioned PH-1110 review session was only held for PH-1110 sections. There was no review session for PH-1111 or PH-1120. Sections for PH-1111 and PH-1120 had no review at all, so often times the TAs first time seeing the lab instructions would be during that lab. TAs in those sections told us that they felt unprepared because they had no exposure to the lab instructions before their lab started, and they don't know who to contact for help. The TAs shouldn't feel this unprepared. If they do, there should be a clear system for them to ask for help when they are confused about a lab. The TAs also have no formal training in using the Logger Pro software. Many TAs say that they hadn't seen Logger Pro before their first lab section; they also said they can get confused while using the software. During a lab section, if a student has a question about Logger Pro that a TA can't answer, there is a big problem. This problem has happened before. The TAs should feel comfortable navigating Logger Pro. They should at least be familiar with the software, if they haven't mastered it by the time labs start. The TAs should have some formal training in Logger Pro.

On a different note, sometimes the less experienced TAs will over-help the students. For example, a student could ask a question, and the TA would give away the answer instead of guiding the student toward the answer. Over-helping decreases the education value of the labs, because the TAs are doing the student's work for them. However, over-helping is only a problem with less experienced TAs. As TAs gain more experience, they get better at helping the students without excessively holding their hand through the lab. A proper training for the less experienced TAs would give them evidence to help them mind the line separating constructive help and excessive help. Even setting up the newer TAs with the experienced TAs to help them find that line would be beneficial.

The main issues with TA training were:

- No review session for 1111 and 1120
- No Logger Pro background
- Over-helping from inexperienced TAs.

The labs would benefit from the TAs receiving better preparation in those areas.

Time Management:

Time management is a topic frequently brought up by the TAs. Every lab section has a set 50 minute period during which the experiment is conducted in the lab under supervision of the TAs. A few labs require 2 sessions on different days. A 50 minute time period can be more than enough, just enough, or not enough, time based on certain factors in the lab section. Those factors include the length of the experiment, and the amount of confusion among the students. The labs should be timed so that students don't feel rushed to finish their experiments. However, that isn't always the case.

For the most, part 50 minutes is enough time to finish the experiment in a lab. A typical lab section will start with the TA explaining the lab for about 5 minutes. The TA will usually start by giving a rough outline of the lab instructions, while using board drawings as a visual aid. To save time they will address specific problems that students in other sections had. Finally, the TA takes questions from students, the whole introduction takes about 5 minutes. Students spend the next 5 minutes or so setting up the experiment, giving them about 40 minutes to complete the experiment and collect data. 40 minutes is usually enough time. The students obviously have questions during the experiment too, but they don't spend much time waiting for TAs to answer their questions. There are 2 TAs in each lab, so they can get around to every question quickly, even during the most confusing labs.

However, if the TAs are scrambling around to answer questions, they can feel rushed. Instead of helping students understand concepts, they just feed students answers. TAs and students shouldn't feel rushed during the lab. When people are rushed the educational value is lost and the labs become a chore that students just want to finish. Some labs require more than 50 minutes because students had too many questions that sidetracked them from the experiment. Usually rushing was the case with labs early in the term because the students are not familiar with Logger Pro. Examples of this problem were apparent in PH-1110 lab 2, and PH-1120 lab 3. In these lab sections every group had many questions about the experiment and the software, to the point where the TAs were overwhelmed. As a result the TAs panicked, and started worrying about getting to every question more than giving a quality response. The students then had to rush to finish their experiments, their work was sloppy, and the education value of these labs suffered.

There are also cases where labs had two 50 minute periods which were not necessary. Certain laboratories do require 2 days, such as PH-1111's Pendula Experiment, but other labs do not. Shortening these labs would provide students with more opportunity to complete the more time consuming experiments. The TAs and the students shouldn't be rushed in lab. The result is poor lab quality. To maximize the quality of the labs, time management needs to become more of a priority.

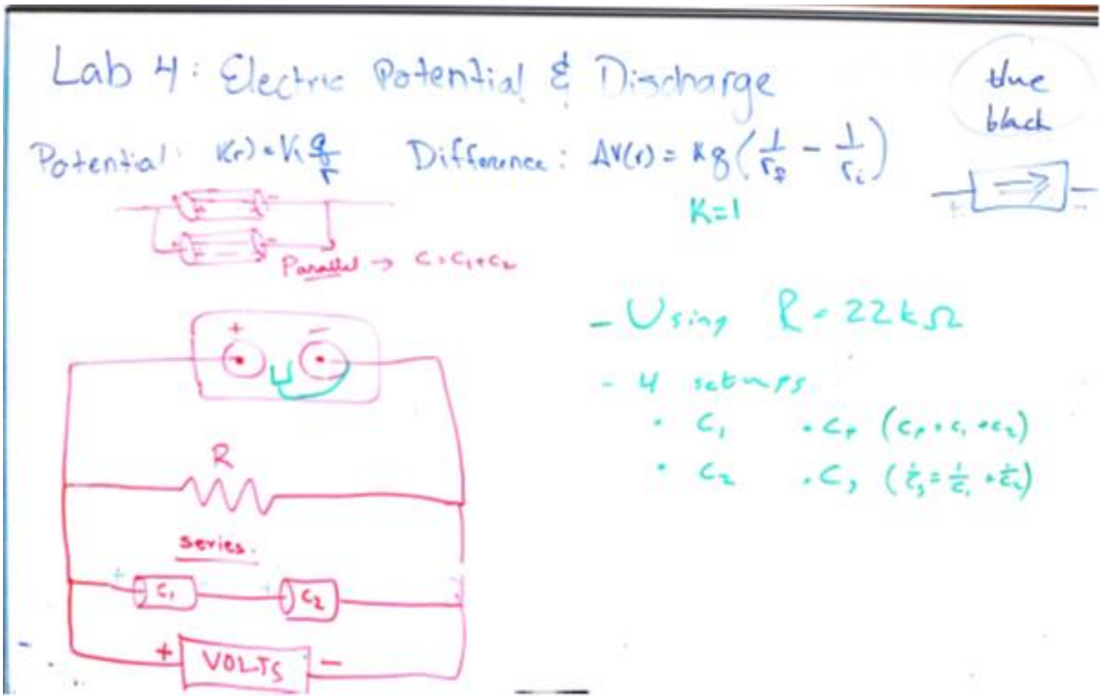
Whiteboard Drawings

In order to introduce students to each experiment, the TAs provide notes on the board with information about the experiment. The content included on the board covers a wide range of information, and typically includes a brief overview of the procedure, important diagrams that are not included in the instructions, procedure clarifications, and due date information.

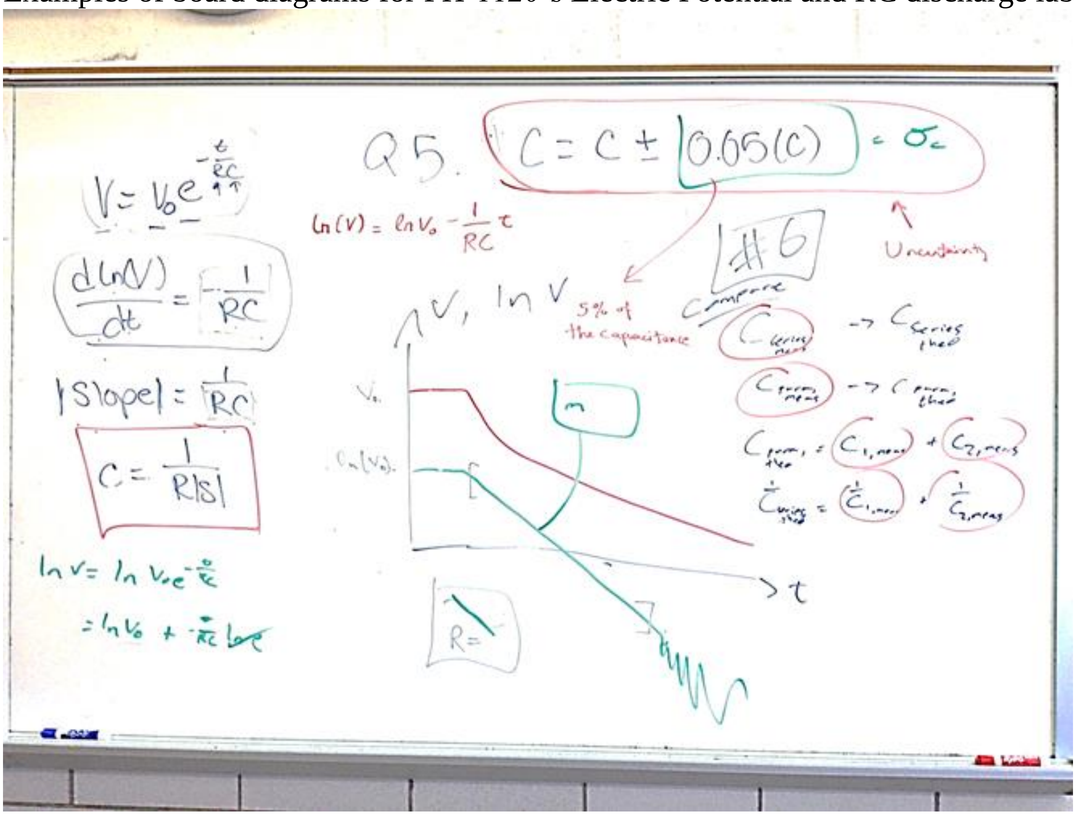
One of the largest problems with the board diagrams is that the information provided to each class may vary widely throughout the week in which the lab is administered. In most cases, at the beginning of the week, a single TA will write the initial information about the lab on the board. While most of the board is not usually erased until all sections have completed the experiment, many TAs will add, remove, or modify specific details on the whiteboard before presenting the information to the class. Therefore, because not all classes have access to the same information, it makes it difficult to grade lab reports uniformly.

The board drawings were often used by TAs to assist students in understanding complicated or unclear sections of the lab procedures. For instance, in the PH-1120 and PH-1121 labs, which regularly require students to construct electrical circuits, the TAs almost always included hand drawn copies of the circuit diagrams. In general, the diagrams provided on the board tended to be more useful and easier to understand than the digital counterparts included in the provided lab instructions.

However, while the board diagrams were typically especially helpful in giving students a clearer understanding of the lab procedure, the lab drawings on occasion provided students with information that should have ideally been discovered through either experimentation or careful consideration. For instance, during some experiments, students were provided with sketches of the graphs that were to be collected during the experiment. Instead, TAs should make an effort to ensure that results (the shape of a data curve, for instance) are not provided to students. Otherwise, the experiment is largely invalidated and students are denied the opportunity to evaluate the results of the experiment for themselves.



Examples of board diagrams for PH-1120's Electric Potential and RC discharge lab.



Examples of board diagrams for PH-1120's Electric Potential and RC discharge lab.

Laboratory Equipment:

Lab equipment is an important part of a successful lab. The lab equipment used in the PH-1110, 1111, and 1120 labs range from simple pulleys and carts to motion sensors and force plates, but all are essential to their corresponding experiment. All lab equipment must be in good enough condition to be used in the experiments. If the equipment is faulty, unnecessary error is added to the experiment, and the quality of the lab decreases. Making sure the lab equipment is functioning properly should be a major priority.

In most circumstances, the laboratory equipment worked as expected. The TAs typically made an effort to warn students of challenges that may arise when working with the lab equipment. For instance, in labs that utilize position sensors, most TAs made an effort to warn students that each sensor has a dead zone in which it will not capture any motion. The length of this zone typically extends approximately 6 inches out from the sensor, but some sensors have larger dead zones than others. Despite this, however, in a few instances there were issues that made it difficult for students to complete the experiment. In one case, for example in PH-1120 lab 3, one group's power supply broke. It took a long time to replace the power supply because there was not a backup readily available. This really held up the lab section because one TA was gone for some time looking for a power supply, and a lot of the groups needed assistance. There should have been a backup power supply in the lab. There should probably be backups for all equipment in case something goes awry. In PH-1120 lab 6, as a result of the equipment failure, the group with the defect was unable to collect any data. The TA instructed one lab group to mail their data to another group, so that the other group could submit a lab report. Obviously, this lab was a total failure for that group, but only because the equipment failed on them. Again there should have been backup equipment in place. Instead there was a group who didn't collect their own data, and had to use another group's data.

Excessive TA Intervention:

The labs are meant to be an example of the experimental process for the students. They are supposed to work through the lab in groups in an effort to find something unknown by performing an experiment. However, this experience can be hindered if the TA's get between the students and the experiment. There were times that TA's would be rushing around the lab answering questions, to the point where they became overwhelmed, and spent less time helping each group. As a result the TA's ended up giving away answers instead of steering groups in the right direction.

The students will only benefit from the labs if they are the ones putting in the work. Instead of getting bailed out of a problem by a TA, students should work through the problem with TA help. If the TAs are the ones doing the work, then the students gain nothing. For example, in PH-1120 lab 4 a group asked a TA a question about building their circuit. The TA responded by building the circuit for the group. Obviously the students won't learn anything about building circuits if the TA does it for them. It is a good thing that TAs are eager to help students but they have to understand that the labs are for the students to work through. The labs should challenge the students. They can ask for help but ultimately it is up to them to complete the experiment and worksheet.

In most cases this problem arises as a result of poor time management. If many groups have questions to be answered and the lab is short for time, then the TA will be rushing around to answer every question. If the TA's are rushed then they are more likely to feed students an answer instead of teaching them to find it themselves. This problem was noticed, for example, in PH-1120 lab 6 where TAs were rushing around because there are two experiments in this lab. Because this lab was so pressed for time TAs would give away certain values in the experiment if the students could not find the values themselves. The TAs said that they did not want it to come to this, but they had no choice, otherwise the group would not have finished the experiment.

Excessive TA intervention is definitely the product of other factors. As previously discussed, if a lab is pressed for time, the TAs can be forced to give away unknown values to the students in order to finish the lab on time. TA training also ties into this issue, because newer TAs don’t know where to draw the line between helping and hand holding. Excessive intervention is a byproduct of larger issues in the lab. Once those issues are addressed excessive intervention problem will probably dissipate as well.

Lab Analyses

In the following section, we provide our analysis of each of the PH-1110, PH-1111, PH-1120 and PH-1121 laboratories.

Expressing Uncertainties of Experimental Data

The "Expressing Uncertainties of Experimental Data" lab is the first lab that is held in PH-1110. This lab is relatively simple, and serves mostly to familiarize students with both data recording and lab submission.

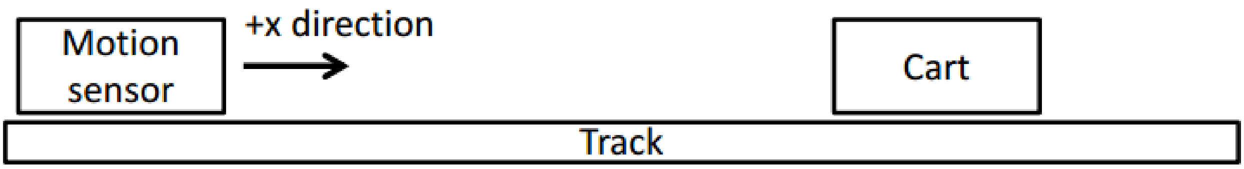
In this lab, students are taught how to properly express results. Students are not given any experiment to conduct. Rather, they are asked to place a series of values into a spreadsheet and present the average and standard deviation in a "standard form". While this lab makes an effort to prepare students for future labs, the worksheet is especially unhelpful because it does many calculations for the students. Instead, students should practice calculating mean, standard deviation, and uncertainty by themselves.

Additionally, it should be emphasized that to get meaningful and accurate data, it is often advised to conduct multiple trials. While this may be clear for the majority of students, some may not understand the purpose of repeating the process in columns F-H of the worksheet multiple times.

Understanding Graphs of Motion

The Understanding Graphs of Motion Lab focuses on:

- Familiarizing students with the basics of Logger Pro
- Teaching students to capture clean, readable data using lab equipment
- Teaching students to translate motion into readable graphs
- Teaching students to interpret graphs and make conclusions based on data



In this lab, students are given a motion sensor, a cart, and a track. This lab is very introductory, and serves mostly to familiarize students with collecting data and using Logger Pro. Students are given a variety of Logger Pro graphs and are told to trace the shape of the graph by turning on the motion sensor and dragging the cart along the track.

There were a few areas that students seemed to have trouble with. Firstly, the motion sensors have a dead zone of about 6 inches. Any motion inside that range will not be captured correctly. While the TAs were very clear with warning students about the sensor dead zone, some students needed to be reminded again. The instructions make no mention of this shortcoming of the sensor and should be adjusted to explain this limitation.

Additionally, some students encountered dramatic spikes in the sensor's output. We found that most of the time, the spikes were a result of the way that students were holding the cart as they moved it along the track.

In one case, a pair of students needed to unplug and reboot the sensor in order for it to output accurate measurements. While this isn't a frequent issue, it might be useful for students to understand that equipment does malfunction on occasion. A small troubleshooting guide for diagnosing issues with the lab equipment would speed up the lab process.

Because this is the first lab to utilize the Logger Pro software, it would help immensely to provide students with a manual for the software. This would not only allow the TAs to spend more time answering questions about physics and less about the software, but would also likely allow students to complete this lab (and future labs using Logger Pro) in a more timely manner.

While this lab is not very intellectually challenging, it does a decent job introducing students to the structure of the physics labs.

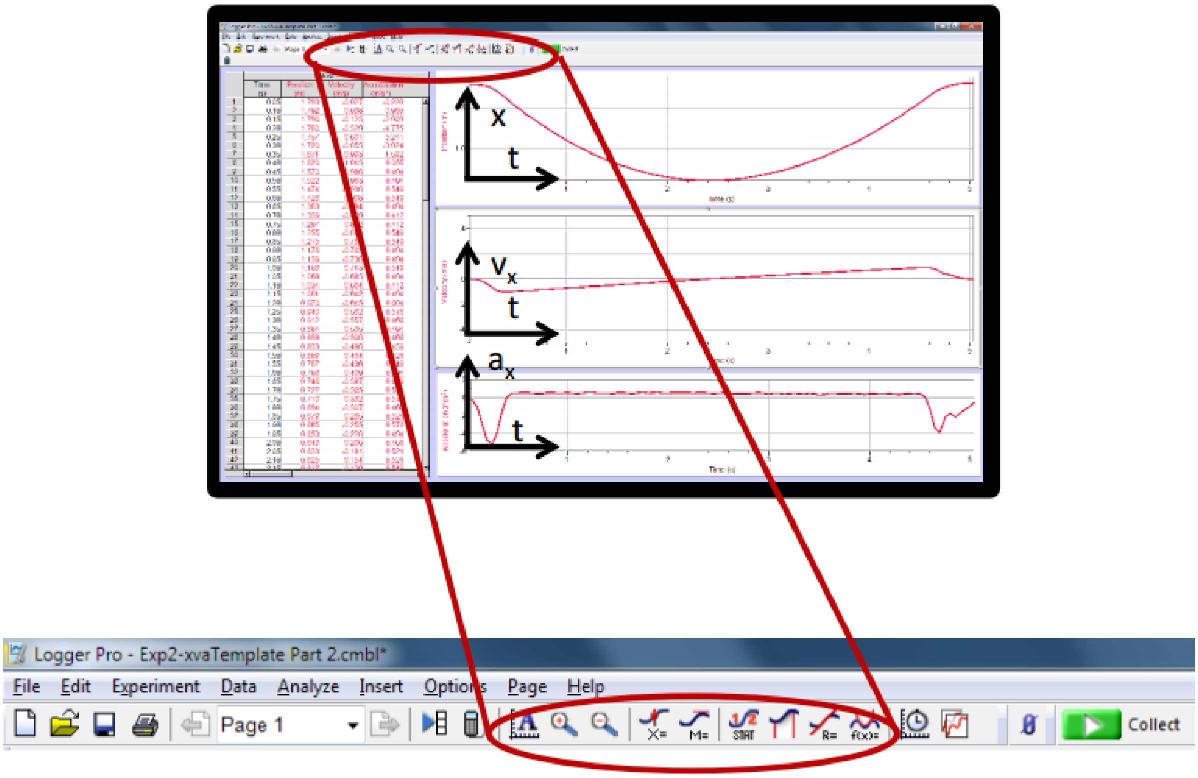
One-Dimensional Kinematics

PH-1110's One-Dimensional Kinematics Lab serves to:

- Increase student familiarity with interpreting graphs of one-dimensional motion
- Teach students to measure displacement, velocity, and acceleration in different ways
- Increase familiarity with the Logger Pro software

In this experiment, students are given a cart, a slightly sloped track, and a motion sensor. By giving the cart a gentle push up the track and collecting data with the sensor, students are expected to discover the relationship between position, velocity graphs, and acceleration. Additionally, students will discover that taking the first derivative of a position graph will yield velocity, and taking the first derivative of velocity will yield acceleration.

In the overview page included with this lab is a photograph depicting fully labeled sample data. In order to ensure that students are able to comprehend their own results, no photographs of data should be included in the lab instructions.



Immediately, we noticed that students had a difficult time using the Logger Pro software. We believe that a quick, ten minute Logger Pro presentation would be extremely helpful in reducing the volume of software related issues throughout the course. This presentation could be given to students during conference, or at the start of the lab. The students were not the only ones that felt unaccustomed to using the software. Some of the TAs admitted that even though they were familiar with the lab material, they did not have enough exposure with Logger Pro to help students as much as they would have liked. We noticed that on multiple occasions, one TA needed to explain certain aspects of the software to the other.

One of the most apparent difficulties with the software throughout this experiment was with the way that Logger Pro displays data that has been highlighted with the mouse. When highlighting regions of data in Logger Pro, there are two boxes that students see:

- A dark gray box – showing the highlighted data
- A light gray box – showing the highlighted time interval.

One group had trouble getting the integral of their position graph because they misinterpreted the selection box. They thought that the light gray box was showing the entire selected region. As a result, they recorded incorrect data into their worksheet. Thankfully, they noticed their mistake and the TA was able to guide them in the right direction. However, looking around – we noticed that there were at least two other groups that made this mistake and did not seem to realize it.

This lab was not very challenging for students, and most groups were able to finish in about thirty minutes. Collecting data for the displacement and velocity was not very difficult for most students – but reading and interpreting the on-screen results seemed to be more challenging. Because students were able to finish with so much time left over, perhaps some time could be taken at the beginning of the lab period to better introduce the software to students.

Free-Body Diagrams

The Free-Body Diagram lab serves to:

1. give students experience in analyzing the motion of two interconnected objects with linked motion.

2. Explore the relationship between friction, acceleration, and angle

In this lab, students place a cart on top of a ramp with a pulley at the top. The students are told to push the cart down the ramp and calculate the angle of the ramp and the magnitude of the friction of the cart as it moves up/down the track.

One of the largest problems with this lab (and other 1110/1111 labs) is the lack of clear diagrams within the lab instructions. On the “overview” section of the lab procedure is a photograph of the lab setup, but it is very difficult to set up the experiment with just this picture. The TA drawn board diagrams were much more effective, and ideally, these should be included in the lab instructions.

While the TAs were able to answer most student questions, we did notice that one student got their string stuck on the edge of the track (instead of on the pulley). As a result, the student had a difficult time performing the experiment and needed to re-conduct this portion of the lab. In order to prevent this from happening in the future, it would be helpful if the TAs warned students to double check that their setup is correct before collecting any data. These kinds of reminders are especially important in the early labs because the majority of students have not yet developed good lab habits.

Additionally, students should also be careful to make sure that the cart is placed properly on the track. One student was unable to get his cart to enter equilibrium. At the bottom of the track (close to the surface of the table), the cart would slowly rise. The cart was not seated properly and therefore the student was getting unexpected results in his data.

Like the PH-1111's Lab 2, students encountered a variety of problems using Logger Pro. One student was trying to open the Logger Pro template on his personal laptop. Apparently some students do not realize that the Lab computers are the only PCs equipped with the software. Giving students access to Logger Pro at home would not only allow students to increase their familiarization with the software, but also enable to students to work with (and view) their data after the end of the lab period.

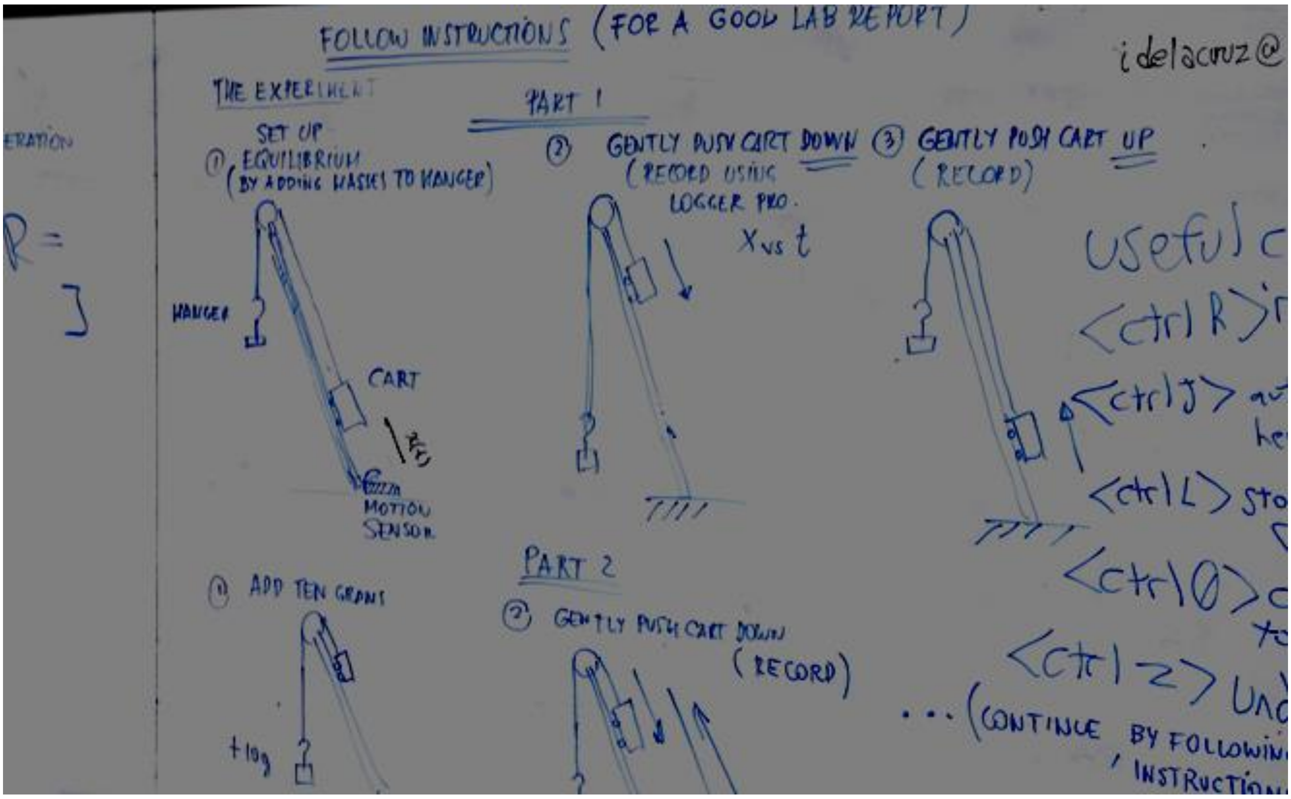
We also noticed that there was a large amount of confusion in finding the least squares fit using Logger Pro. Because lab #1 has students calculate the least squares fit by hand, many students seemed to think that this calculation could be done "at home", whereas in this lab, the instructions are describing logger-pro's linear fit tool.

One question that students asked a few times: *"When I am doing part 2 (pushing the cart down the track and letting it come back up), should I be recording the part when the cart moves down the track, or up the track?"*

Students were not realizing that even though the velocity and position were changing (from positive to negative), the cart accelerates at a constant rate. So the answer is both.

The instructions at the end of part 1 were challenging for some students to understand. It should be made more clear that students are expected to gently tap the cart, let go, and allow the cart to coast.

Finally, the TAs noted that there is a lot of variation in the amount of effort that lab groups put into the lab worksheet. Some students do much less than is expected, while others do much more than expected. The TAs recommended that the worksheet expectations are made more clear to students



The Mass-Dependence of Friction

The goals of the Mass Dependence of Friction Experiment are:

1. Acquire a better understanding of the relationship between mass and friction.
2. Gather data and acquire values for N, f, and μ.

All PH-1110 labs have an "Overview" page that is attached to the lab instructions. In Lab 4, the overview section does a good job introducing the lab to students, but is very undescriptive in its description of the lab's "central concept":

"It is possible to both predict and verify behavior, as you will do in this experiment."

It is good to see that the overview does not reveal the conclusion of the lab, but it still does a poor job explaining the objective of the experiment.

Immediately, we noticed that Part 2 of the experiment tells students to "set up the equipment as for the kinematics experiment, where you detected the motion of a cart on a slightly sloped track". The underlined portion links to PH-1110's Lab 2. This link should be removed and the set up instructions should be copied into this lab procedure. The current layout is not ideal because if the setup for Lab II needs to be changed in the future, it could potentially conflict with the intended setup for this lab. Additionally, if the URL for Lab II ever changes, then the link in these instructions will break as a result. This same mistake is made later on in the procedure – the instructions tell students to “follow the standard form that you learned in Part I of the uncertainties experiment”. (the underlined text links to PH-1110’s Lab 1). Additionally, telling students to follow the same format for representing results may give students the idea that there is a single, universally applicable method for reporting results. While a standard form is useful for organization, not all experiments will necessarily require that data is presented in the exact same way. Different circumstances may require a different approach – and this should be made clear to students.

Next, because this is many students' first year at WPI, standard deviation is an unfamiliar concept to many. The TAs commented that many students do not have the necessary statistics background. In addition, some students were not familiar with the equation:

$$\mathrm{sd} = \mathrm{SQRT}\ \{\ [\ \textstyle\sum_i (x_i - x_{ave})^2\ ]\ /\ (n-1)\ \},$$

TAs recommended that standard deviation be briefly covered in conference so that students are more familiar with it when coming to lab.

In addition, the beginning of the lab instructions tell students to draw the free body diagrams in a notebook or on a piece of scratch paper, but the worksheet contains a section for the free body diagrams. The instructions should be cleaned up for consistency. Since the worksheet designates a spot for a free body diagram, the scrap paper option should be deleted.

There were also some problems with the lab equipment. One of the largest issues that we noticed with the equipment is the sensor dead zone. The sensors will not correctly collect data from anything that is less than ~6 inches from the sensor. The time spent getting lab equipment working as it should takes away from the time that students have to complete the lab. Additionally, we noticed that having more than one instance of Logger Pro open on a single computer prevents the sensors from being detected. The TAs noted that in some cases, the problem can only be fixed by completely rebooting the computer. Students need to completely reboot the computers to solve the problem.

Finally, in this experiment, most of the tracks are set to (approximately) 10 degree angles. Reducing this angle will make the force of friction more apparent.

Overall, this lab teaches students some important concepts about the relationship between mass and friction and is definitely one of the more effective labs that is offered in PH-1110. However, the quality of the lab could benefit greatly from the consideration of the above suggestions.

Conservation of Energy

This lab focused on observing the mechanical energy of a mass-spring system over time. By completing the experiment, students are expected to observe that total mechanical energy is conserved in the system. While this lab is useful in teaching students about the conservation of energy, there are some opportunities for improvement within this experiment.

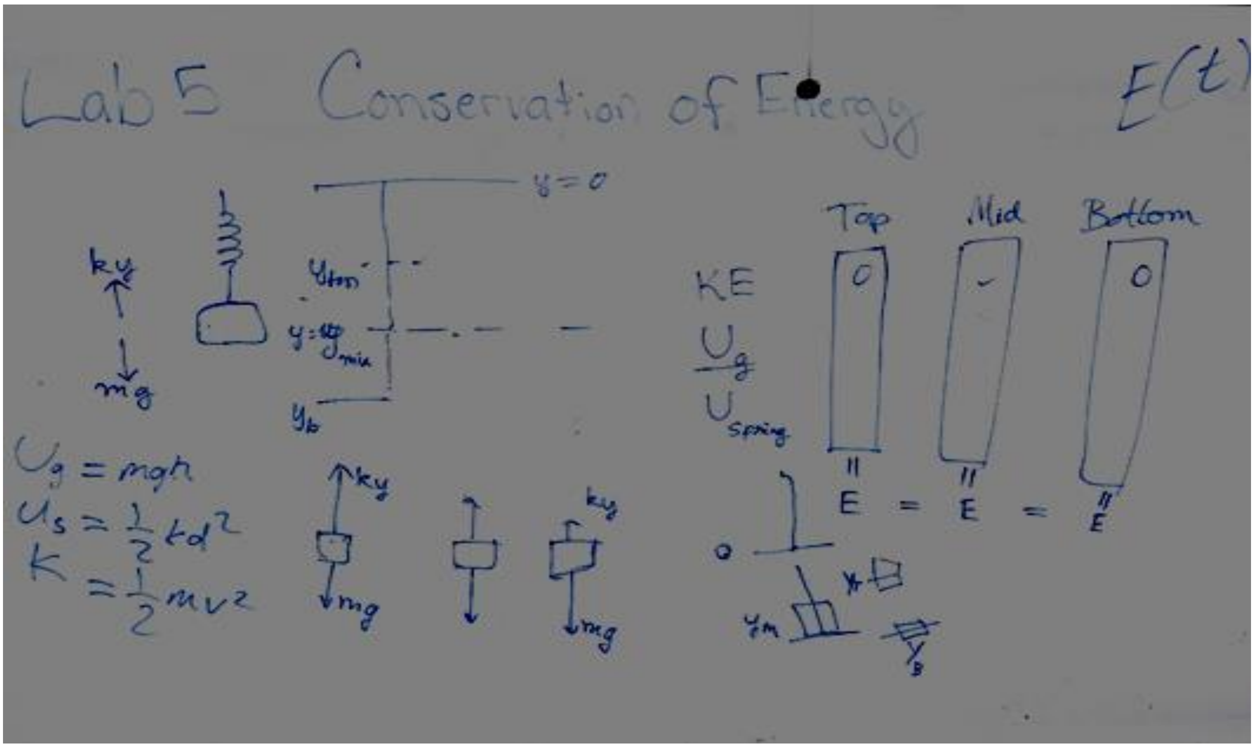
First, we noticed that many groups were pulling their masses too far down. This makes data collection more difficult because it can cause the spring system to oscillate faster than the sensor can accurately record. By making smaller oscillations (as intended), the resulting graph has points that are much closer together and produce much better results. The lab instructions tell students to pull the spring down “a few centimeters”. Some students took this to mean 2-3 cm, while others pulled their masses much further (5-6cm).

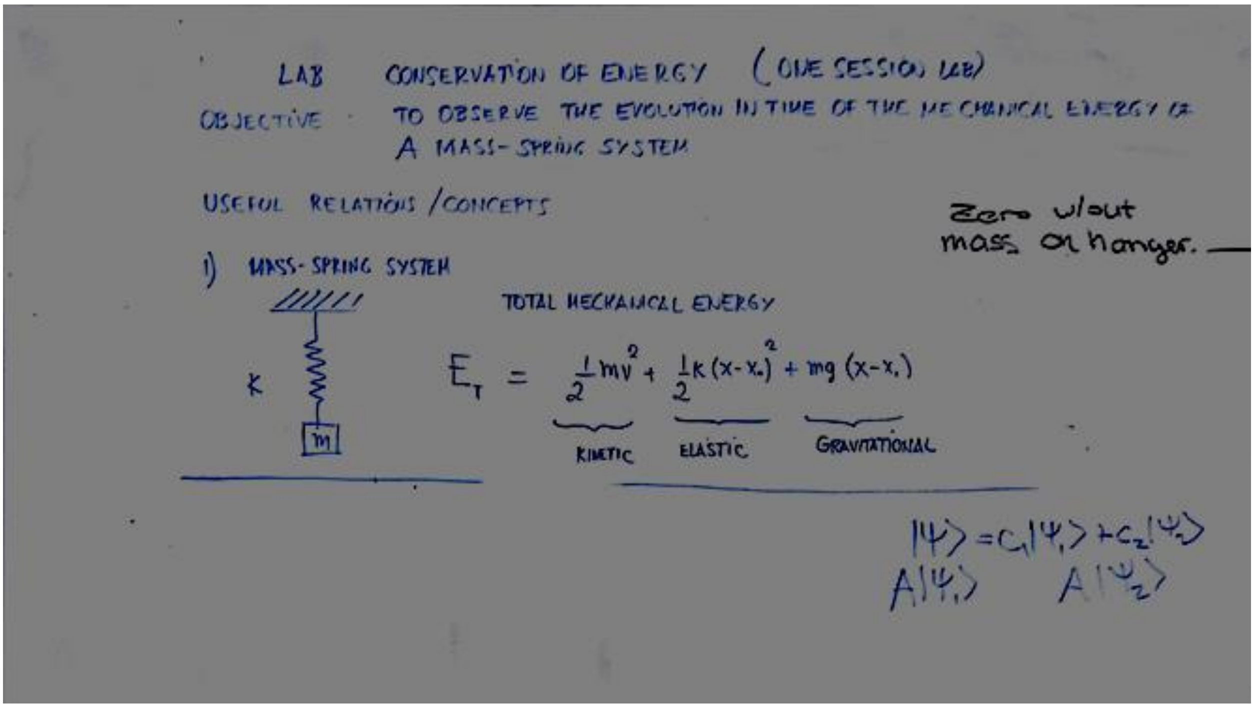
Some students had difficulty creating the trend line for the data in Logger Pro. This is likely a result of a lack of student familiarity with the software. However, some of the trend-line related issues occurred because students were not selecting enough data points. The TAs told students to select a complete cycle within the data for creating a trend line. However, for students that pulled the mass too far down, one oscillation might only contain three or four data points because the motion sensor can only record data at a specific rate. If the mass is oscillating too quickly, then the motion sensor will not collect enough meaningful points within a single oscillation. While this was not much of a problem for the 1111 students, multiple groups in 1110 needed clarification on this point.

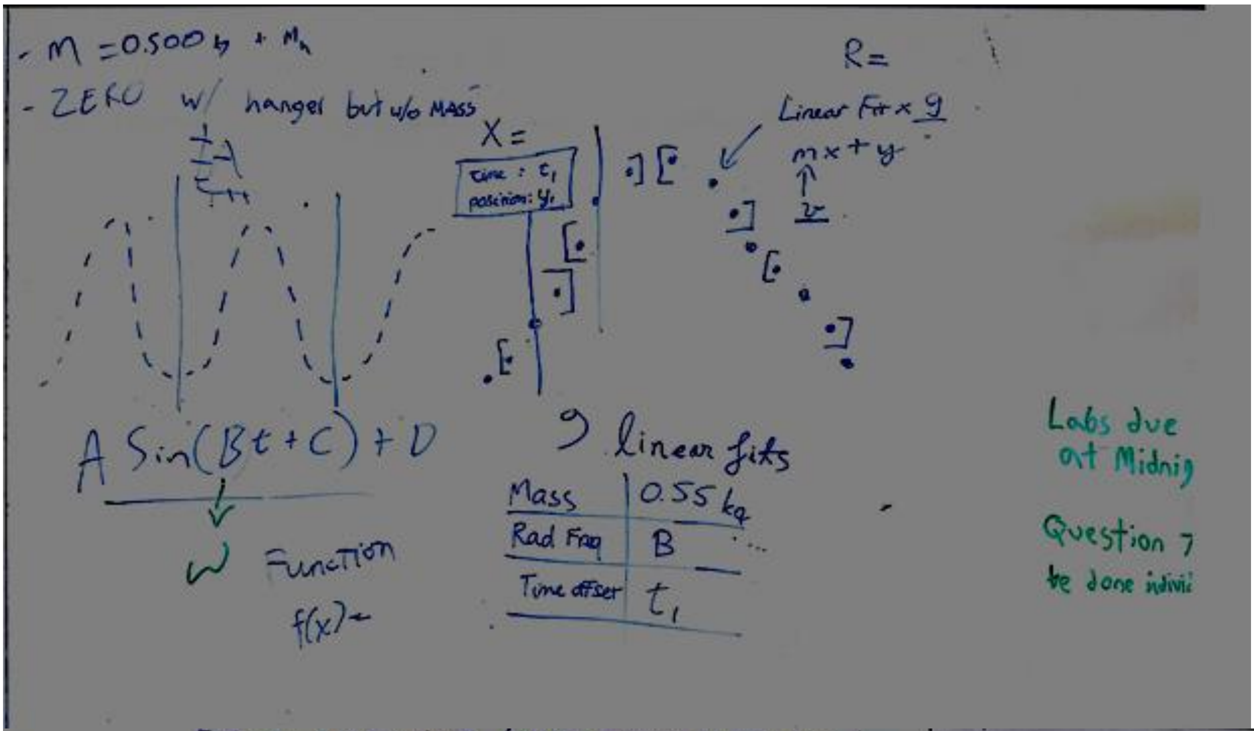
In order to complete these labs, students are required to utilize the formulas for gravitational potential, elastic potential, and kinetic potential energy. In both PH-1110 and PH-1111 labs, these formulas are provided to students on the board. While giving these equations to students certainly helps participants complete the lab on time, we believe that the equations should be removed from the board. This way, students are forced to think more about how to complete the experiment, and are not merely copying the procedure (and answers) off of the board.

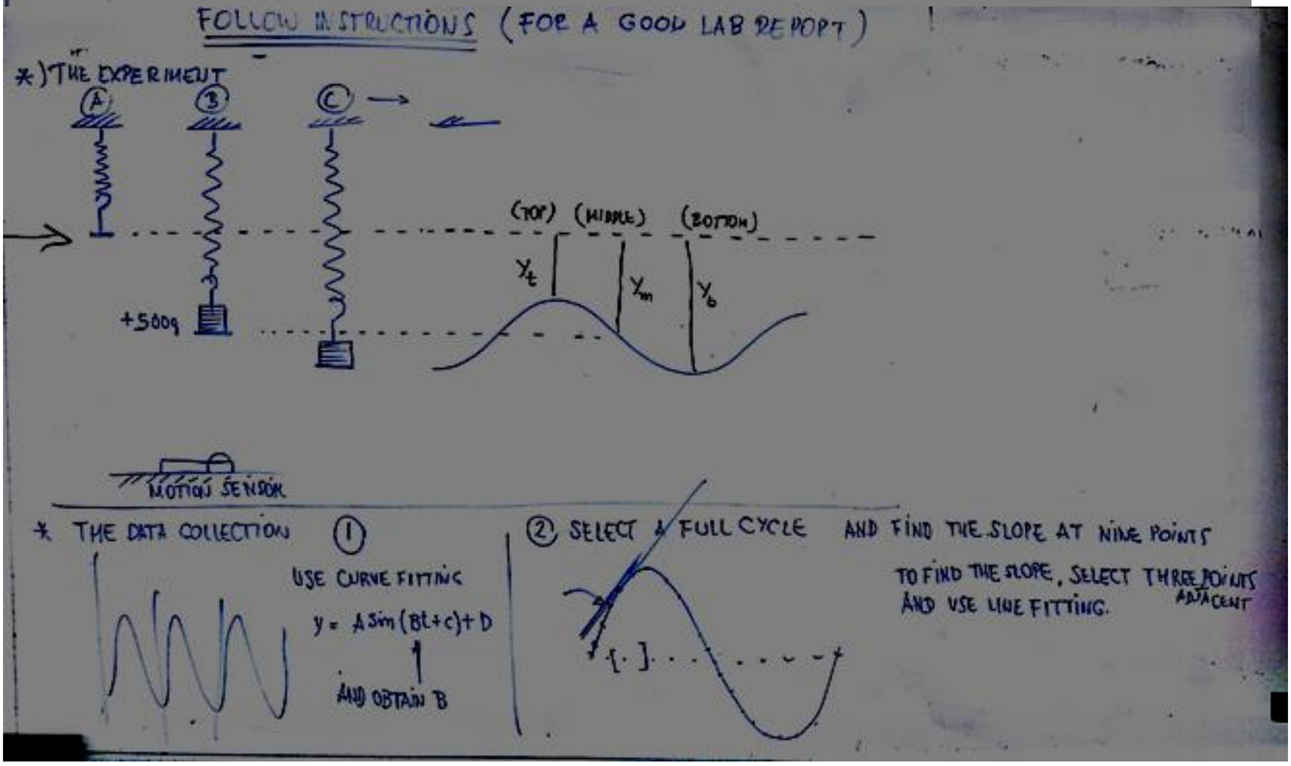
For similar reasons, we think that students should decide for themselves which formula to use when applying a least squares fit to their data within Logger Pro. Therefore, students should be given the formulas for the different types of least-squares fits, but have to decide which one to apply.

Finally, the end of the lab states that “If all has gone well today, you have confirmed that mechanical energy is conserved for a mass on a spring”. There is a question in the worksheet that asks students to report their results, but the answer is given away by this statement in the instructions. We think that this might be nice for the students to reach this conclusion themselves, instead of being told that this is what they should observe.


Lab 5 Conservation of Energy
E(t)
y=0
Top
Mid
Bottom
KE
U_g
U_{spring}
E = E = E
$U_g = mgh$
$U_s = \frac{1}{2}kd^2$
$K = \frac{1}{2}mv^2$
ky
mg
y_{top}
y_b


LAB CONSERVATION OF ENERGY (ONE SESSION LAB)
OBJECTIVE · TO OBSERVE THE EVOLUTION IN TIME OF THE MECHANICAL ENERGY OF A MASS-SPRING SYSTEM
USEFUL RELATIONS /CONCEPTS
Zero w/out mass on hanger.
1) MASS-SPRING SYSTEM
TOTAL MECHANICAL ENERGY
$E_T = \underbrace{\frac{1}{2}mv^2}_{\text{KINETIC}} + \underbrace{\frac{1}{2}k(x-x_0)^2}_{\text{ELASTIC}} + \underbrace{mg(x-x_0)}_{\text{GRAVITATIONAL}}$
$|\psi\rangle = c_1|\psi_1\rangle + c_2|\psi_2\rangle$
$A|\psi_1\rangle$ $A|\psi_2\rangle$





The Impulse-Momentum Theorem

This lab explores the relationship between impulse and momentum. The experiment involves bouncing a tennis ball on a force plate to observe the impulse of the impact. That impulse is then compared to the change in momentum of the tennis ball to discover the relationship between the two. The students are very familiar with Logger Pro by now, so the software didn't slow down this lab at all. The TAs commented that this was one of the better experiments in the PH1110 labs.

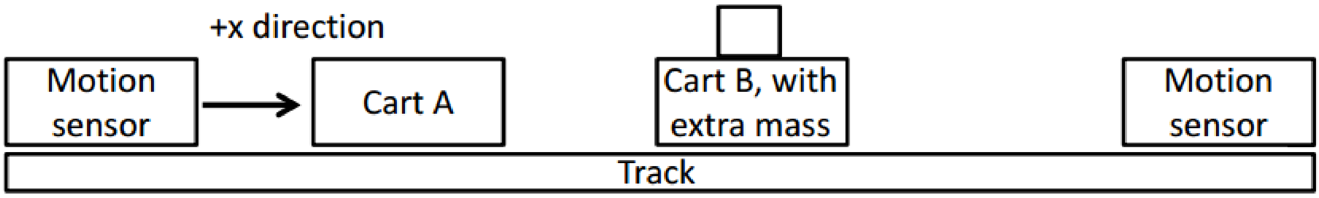
One of the reasons that this lab ran so smoothly could be that the instructions lead the students to a conclusion. A lab running this smoothly isn't always a good thing. If the students just follow the instructions until they prove a theorem then what do they learn? The introduction of the lab instructions introduces the impulse-momentum theorem: that the impulse is equal to the change in momentum. The lab should be set up for the students to explore whether or not that theorem is true. Instead the students follow cookie cutter instructions to reach a conclusion that is stated at the end of the lab instructions.

"If all has gone well today, you will have verified that the change in momentum is equal (or close) to the integral of the force over time, that is, the impulse-momentum theorem is true."

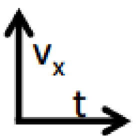
The students cannot draw their own conclusion about the theorem if the correct observation is given to them. The labs should not be a recipe, but more of a general guideline as to what the experiment is seeking to prove. The students should figure out what to do with the data they have collected instead of being told what to do with their data. We suggest omitting the last sentence of the instructions, and making the instructions more vague. Particularly when it comes to the data crunching, that should be on the students.

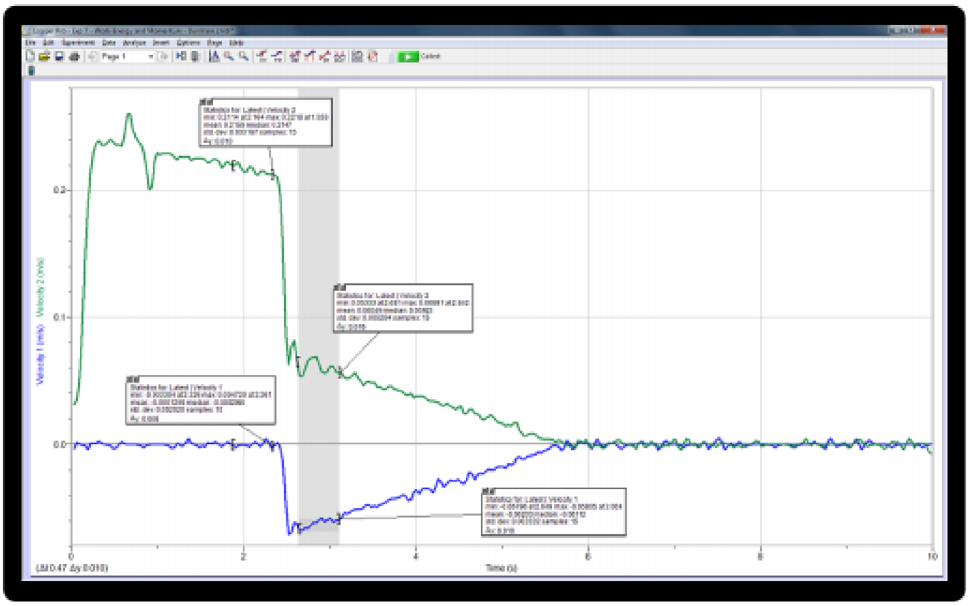
Work-Energy and Momentum

The Work-Energy and Momentum Lab focuses on observing the change in kinetic energy and momentum during elastic and inelastic collisions. To complete this lab, students are given a track on a level surface, two carts, and two motion sensors. One of the two carts has additional mass placed on top of it. Additionally, one cart has a plunger that protrudes from the bumper and can be extended or retracted. When the plunger is extended, the two carts will bounce off of one another. Because both carts have a strip of Velcro attached to the bumper. When the bumper is retracted and the carts are allowed to collide, the Velcro strips will make the carts stick together. The carts also have magnets in them, to help the carts stick.



This lab, like many other experiments in this course, reveals too much information about the intended results to students. For instance, the last sentence of the procedure states, “you will have demonstrated that independent of the materials involved one entity (kinetic energy or momentum) is conserved (i.e. remains the same) during a collision, and the other one is not. The other entity will be very different depending on the kind of collision”. The same problem exists in the worksheet. Question 6 states, “*In your own words*, discuss why the $\Delta K/K_i$ values are very different for the two experiments, yet the $\Delta P/P_i$ values remain approximately the same. Where does the “lost” energy go? How does work get done on the carts?” Finally, in the “overview” section of the procedure, students are provided a photograph of collected data. Screenshots of data should not be provided to students because it gives students something to measure their intermediate results against and defeats the purpose of the experiment.



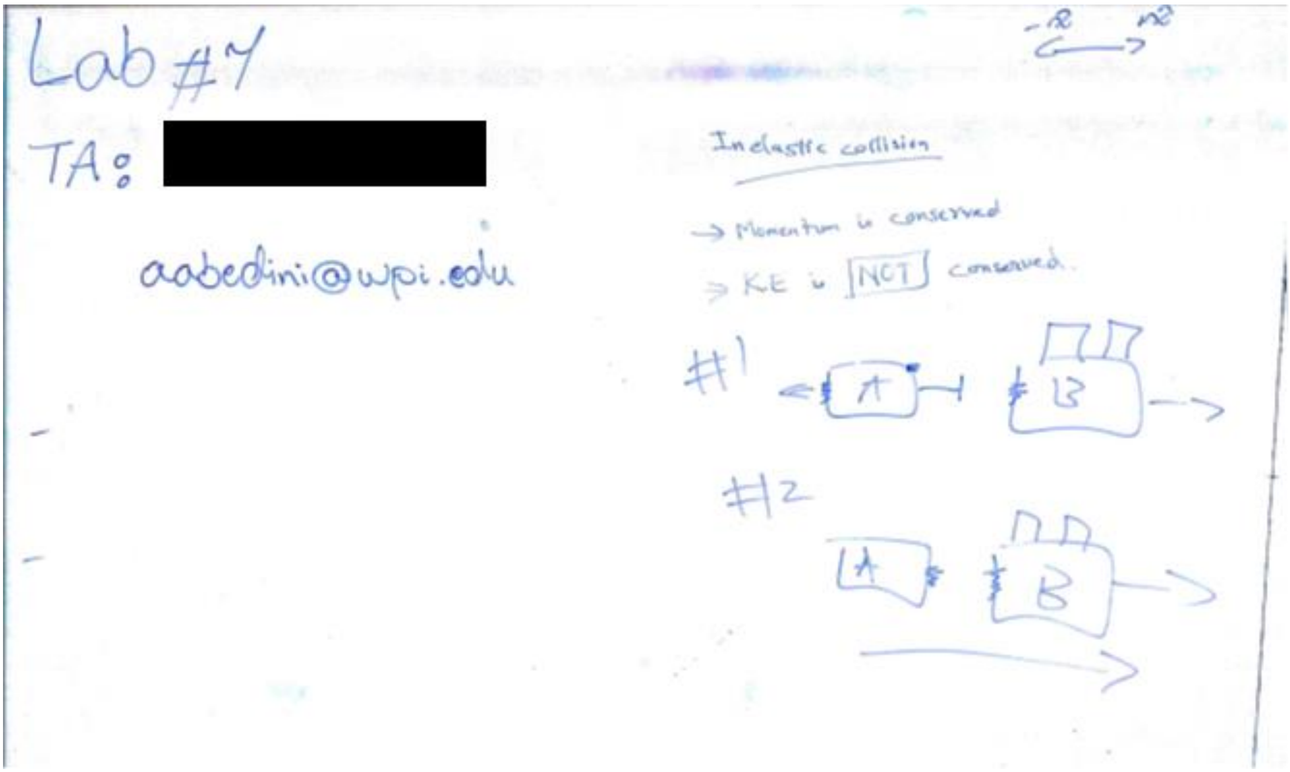


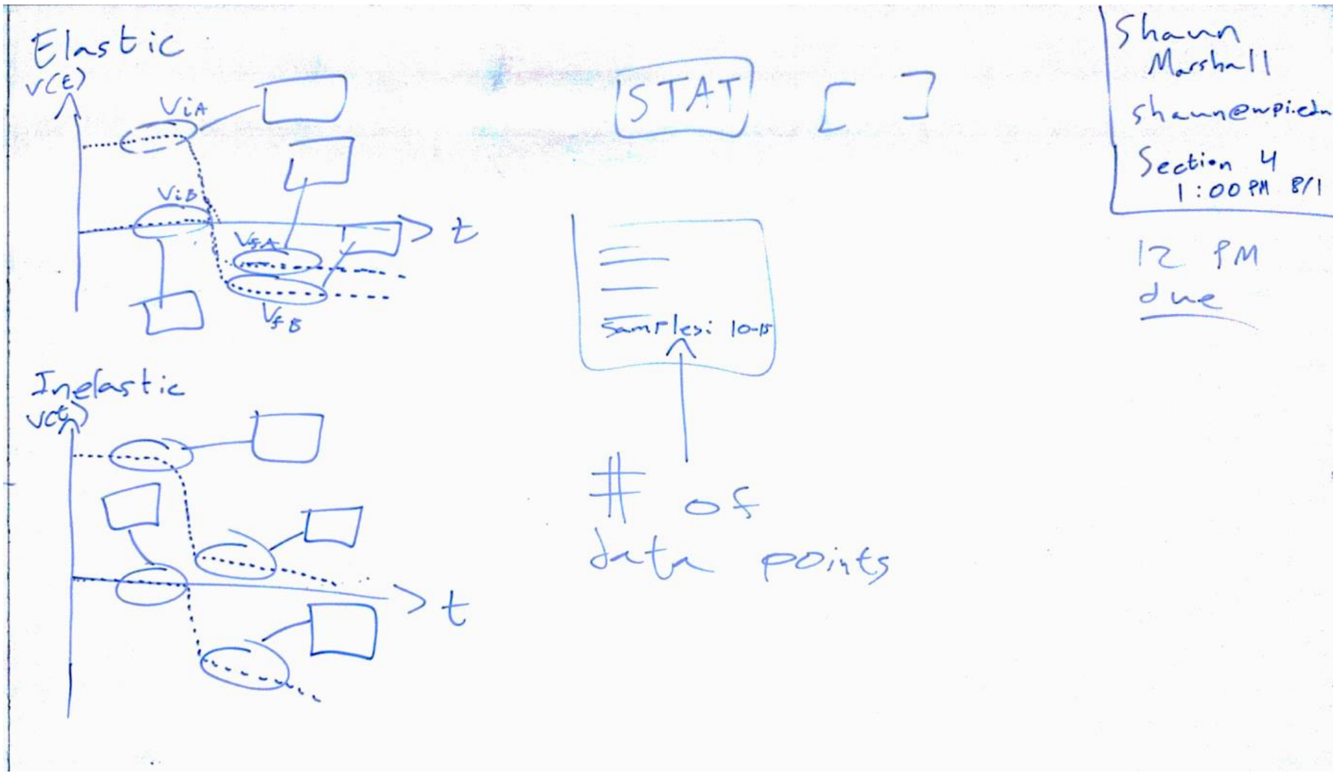
The major flaw with this lab is that students are told that one collision will result in conservation and the other should not – and are then told to verify that their results are in agreement. Instead, students should instead perform the experiment, and then use the results to draw their own conclusions about conservation.

There were also a few minor problems with the equipment during this experiment. For problem 4 of the worksheet, students are supposed to fill out a data table with collision data. One field in the data table is initial velocity. This is obtained by analyzing the data that is acquired through the use of the Logger Pro motion sensors. Since the sensors are not perfect, Logger Pro will detect a small initial velocity even though Cart B is completely stationary. The TA warned students to ignore this inaccuracy and enter 0 m/s into the data table instead. However, while it is true that Cart B is visibly stationary, students should not be encouraged to alter the data that the motion sensors produces because these small inaccuracies are inherently present in all values measured with the motion sensor. Altering only some of the data introduces more inaccuracy than it fixes.

Additionally, two groups seemed to have difficulty determining which portions of their data was useful. These students were selecting the meaningless noise at the beginning and end of their results in addition to their actual data. Including this meaningless data caused some students to have slightly skewed values when using any of Logger Pro's analysis tools. In Lab #0 (or any early lab in the course where there is extra time), it may help to put a greater emphasis on teaching students how to decide if data is relevant or not.

The Work-Energy and Momentum lab is an extremely educational lab and provides students with a real understanding of the underlying physics during a collision of two objects. However, the educational value of the lab is greatly diminished because students are not forced to conduct a traditional experiment. Instead, they are provided the intended results, and merely told to verify that their data matches the pre-provided conclusion.





Static Equilibrium

In this lab, students are tasked with learning about forces, torque, and static equilibrium. To conduct the experiment, each lab group is provided with a force table, a set of mass hangers, and a popsicle stick. By attaching weights to the popsicle stick and hanging the masses off of the force table, students are expected to conclude that the sum of forces and torques are equal to zero when the popsicle stick is placed in rotational equilibrium.

Students attempt to create rotational equilibrium followed by translational equilibrium using a system of pulleys and hanging masses. Calculations and measurements are done by hand as opposed to the usual computerized results (an interesting aspect of this lab).

Like all other 1110 labs, a lab overview page is included with the instructions. In the center of this page is a photograph of the force table and weights. Unlike some of the photographs included in the overview sections of previous labs, this photograph serves as an excellent reference to students and does not reveal any of the expected outcomes of the experiment. Furthermore, we appreciated that in this lab, students are required to make calculations on paper. The overview states, “This experiment will be carried out on a force table, and you shall be making all of the measurements by hand, rather than with computer assistance”.

However, there is still much room for improvement in this lab. Because students are only given an hour to conduct this experiment, few were able to finish the experiment on time. In the lab section that we attended, only one group left before the hour was up. If possible, spreading this experiment out over the course of two lab periods would help immensely. Doing so would not only allow TAs to spend more time helping students, but would also help ensure that students have collected all of the necessary data before leaving the lab.

Additionally, students seemed to have a difficult time performing cross product calculations. The cross product is not taught in lecture, so there might have been students who have never done a cross product before. While the TAs were able to help with some of these issues, perhaps providing students with additional practice before coming to lab would help more students finish on time.

Moreover, at the end of part I, the instructions state, “Calculate the fractional error by dividing the sum of the torques by the sum of their magnitudes. If the fractional error is greater than 0.099, redo your calculations or repeat the experiment.” This statement should be removed.

There is no “experiment” if students are told to repeat the procedure until their data is deemed ‘correct’.

In a similar vein, this lab, like many other PH-1110/1111 labs, reveals the expected outcome to students in the end of the procedure instructions. The last sentence of Part II reads, “If all has gone well today, you will have confirmed that the sums of the forces and torques are equal to zero in equilibrium”. Instead, this sentence should be removed and a question should be added to the worksheet that asks students to draw their own conclusions about the sum of the forces acting on the popsicle stick.

Where many other PH-1110/1111 labs rely on sophisticated software and spreadsheets to help students make calculations, this lab is excellent in the way that it requires students to make the calculations themselves. As a consequence, however, most students were not able to complete the experiment on time. This lab does an excellent job teaching students about rotational equilibrium, but the instructions make it hard for students to analyze their own data and learn from their own mistakes. By removing the unnecessary statements mentioned above, the educational value of this experiment could be greatly increased.

String and Nuts

Since this is the first lab, an introduction is necessary. The TA began the class by demonstrating how to navigate the MyWPI site. After the demonstration, the TA passes out the FCI exam, and the students fill it out. We think that this demonstration is important, it clears up any confusion that first year students have.

Then, the TA read through the experiment instructions, which is a take home. The students are given string and nuts to create a pendulum anywhere on the campus. Students record the period of the pendulum (T) for different lengths of string (l) and different masses (m). Then the students graph their data length against period, and mass against period. Using the graphed data the students create a least-mean-squares fit line and determine the two coefficients (a and b) of the power law equation, $y=ax^b$.

This experiment is a good introduction, but while we have the students in the laboratory shouldn't they just do the experiment there? We're not sure why the first laboratory is a take home experiment; it's also the only experiment that students are required to complete at home. We think it would be better for the students to work together in the laboratory. Since time in the laboratory is scarce, no time should be wasted. The students left after the materials were handed out which only took about a half hour. The students are not forced to leave the laboratory but the TA gives them the option to leave -- an option that every student took. Alternatively, the rest of the laboratory time could be used as a Logger Pro introduction since students always have trouble with the software at first. We would suggest that the second half of the available hour be put toward something productive.

The laboratory instructions expose the students to four important skills; dimensional analysis, improvising equipment, experimental design, and linear least squares analysis. The TA's go over the laboratory instructions with the students by explaining each section in better detail and answering questions the students have along the way. The dimensional analysis section doesn't have too much detail. It identifies the variables on which the period is dependent on and sets up a basic equation based on those variables, $T = K\ L^x\ m^y\ g^z$, where K is a dimensionless constant. This section of the instructions does a good job teaching the students how to set up a basic equation by analyzing the variables that a value is dependent on.

Improvising equipment and experimental design go hand in hand. Students are given a length of string and nuts and told to measure the period of a pendulum for various lengths of string. To do so, they have to improvise with the equipment given, in this case creating a simple pendulum. The experimental design skill ties in with designing the pendulum. Students have to design a functioning pendulum and figure out the best way to record the period while minimizing error.

The last section of the instructions focuses on analyzing the data using a least-mean-squares fit. The instructions first manipulate the power law equation so that it is linear, log(y)= log(a)+ b log(x). Students are given a link that sends the students to a page explaining how to do a least squares fit by hand. The students graph the data they gathered, as a log-log plot, and then perform a linear least-mean-squares fit by hand to get values for unknown coefficients and end with an equation for period. The instructions were very informative but also easy to follow, perfect for a first lab. The instructions also do a good job explaining dimensional analysis, improvising equipment, experimental design, and linear least squares analysis. These are useful laboratory skills for the students to use in future labs.

Force Diagrams for Single and Double Pendula

In the single and double pendulum lab, students are given some string and a few different masses and are asked to create a simple pendulum hanging one of the masses. The students measure the angle created before releasing the pendulum (Θ), the lateral displacement of the pendulum (d), and the tension of the string (T). Then they change the mass and take the same measurements, repeating this process for a total of three trials. After each trial the students draw a force diagram of that pendulum to calculate the tension in the string. After all three trials have been completed the students organize their data into a chart and compare their experimental data to theoretical calculation.

The second part of this experiment requires the students to create a double pendulum system, shown below is a diagram of the system from the laboratory instructions.

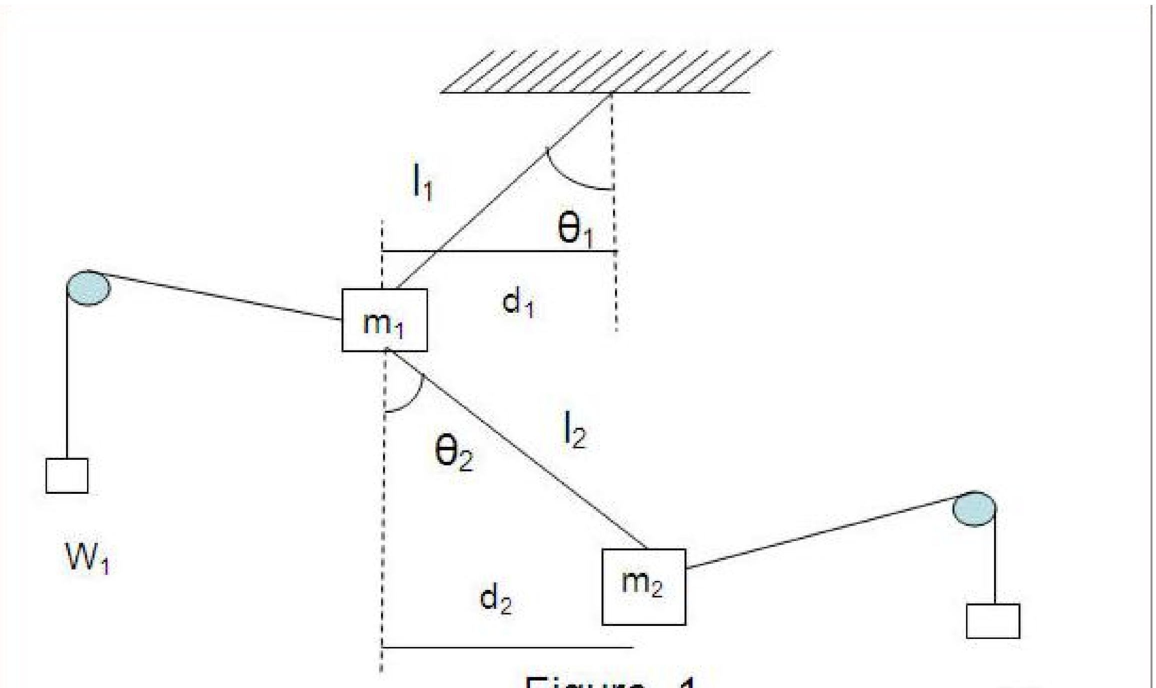


Figure 1

The values for l_1, l_2, m_1, and m_2 are given. Students use different masses for W_1 and W_2 and measure the different deflections, d_1 and d_2, and the angles, Θ_1 and Θ_2.

There were a few noticeable issues with this lab, the first being that it was too long. This laboratory is split into two, fifty-minute sections. The second section is unnecessary, only three groups of about 12 total needed the section to finish the experiment and those groups did not need more than 30 minutes of the second section. We would suggest omitting the second section of this laboratory and instead giving students a single, 50 minute section to conduct the experiment. Since most groups did not need the second session, we think that the time can be put toward another laboratory that needs a second session more. For instance, we think that students would benefit from having more time to complete PH-1111's Conservation of Energy experiment. Part one of this experiment, the simple pendulum, is very similar to the take home lab. Since the students create the same pendulum we would suggest omitting this experiment from the lab as well because the second part of the lab demonstrates force diagrams well enough on its own. The instructions do not present the goals of this experiment well enough. The instructions also could have included a diagram of the simple pendulum since there was a diagram of the double pendulum. Aside from those suggestions the lab ran smoothly. The students created the pendulums without any significant problems and their experimental data was close to their theoretical data.

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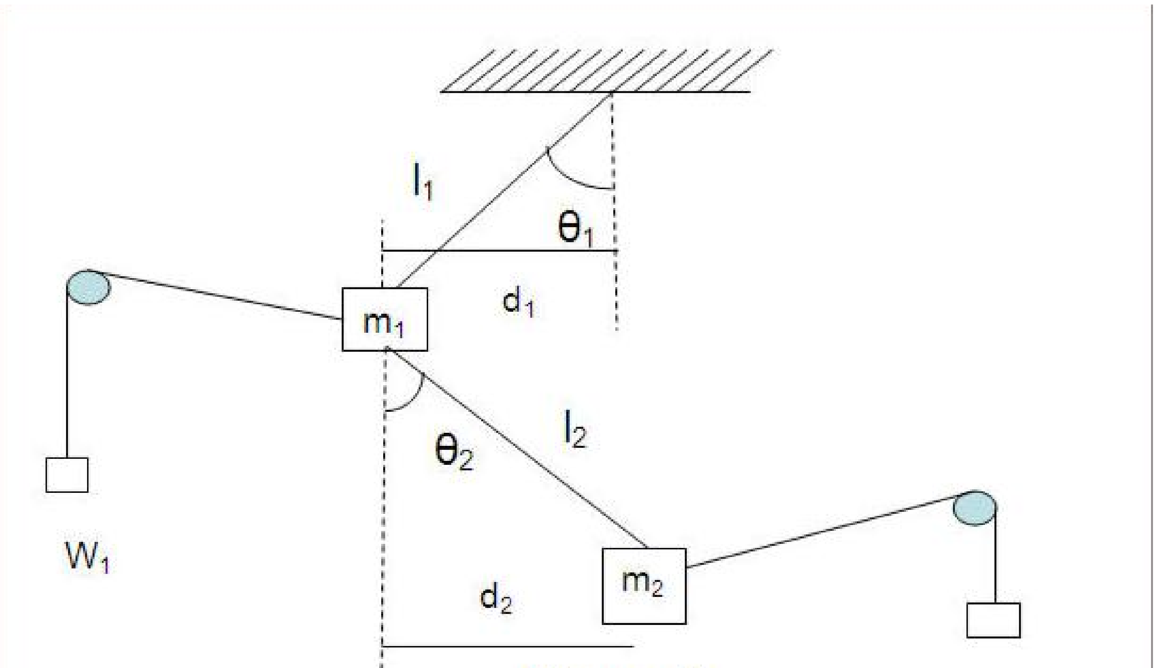

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Cart on a Steep Slope

This lab is called “Cart and Hangar Acceleration” because it contains an experiment that features a cart on a sloped track being pulled by an attached hanging mass or a “hanger”. The experiment is set up with the cart on the slope with the hangar attached to the cart and run up the length of the track. The mass is then looped over the track, using a pulley, so that it is hanging freely. A motion sensor is placed at the bottom of the track to collect data using Logger Pro. In the first part of the experiment the students choose a mass that holds the cart motionless at equilibrium on the track. Once the cart hangar system is at equilibrium the students nudge the cart down the track and record a velocity vs. time graph using Logger Pro. The students then perform a least-squares fit to the graph to get a value for the acceleration down the track. After this experiment is complete the students use a meter stick to find the angle of the track.

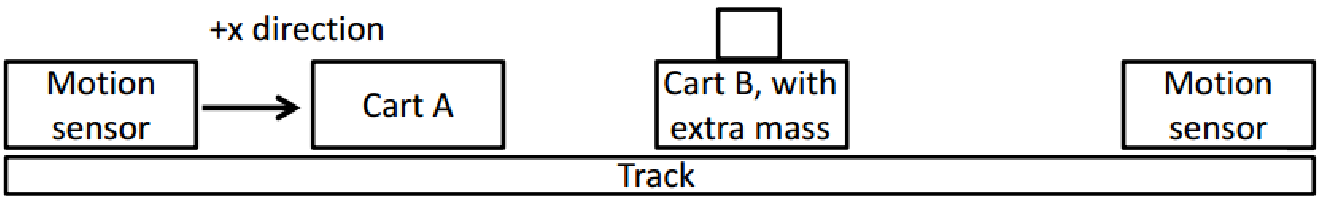
In part 2 of this experiment the students add 10 g to the equilibrium mass from part 1. The students then set the cart at the top of the track and push it down the track so that the hangar pulls it back to the top. The motion sensor collects data again in a velocity vs. time graph. The students perform another least-squares fit to this graph to find a downward acceleration and an upward acceleration. This labs function is to teach students the relationship between friction, acceleration, and angle. The experiment does a great job of exploring that relationship. We wouldn’t change the procedure at all. There are a few minor bugs in this lab mainly in the set up of the experiment. One group of students did not use a pulley, another group had to ask how to push the cart down the track, one group pushed the cart too hard and it smashed into the motion sensor. It seemed clear that the students were confused about the procedure. We suggest a TA demonstration at the beginning of the lab along with the usual introduction that the TA’s give. During the introduction the TA’s drew diagram for each part of the experiment. We think it would be more helpful if these diagrams were included in the instructions. The students struggled with Logger Pro again, mainly with the least-squares fit function. Lab 1 has the students calculate the least-squares fit by hand so many students thought this part of the lab could be done at home. Other issues with Logger Pro were mainly problems navigating the software. We suggest some training in using Logger Pro for the students.

After one lab section Alec and I caught up with the two TA's to ask for their thoughts on the first few labs of the term. The TA's told us that they also find Logger Pro difficult, they have no training in using the software either. Having the students confused with the software is one thing, but when the TA's do not offer enough assistance that is a serious problem. One TA expressed that there is a disconnection between the lab TA's and the professors. The TA said that he/she had only talked to the professor of his/her section once before the term had started, and then never heard from him again. The TA also suggested a weekly or biweekly meeting between the TA's and the professors to reinforce what is being taught in the class and how it pertains to the labs. The TA's also told us that they see a large variation in the amount of effort that each group puts into the lab. They also said that there is no specific grading rubric so it can be difficult to grade the labs. The TA's suggested a clearer grading rubric with a more specific guideline for grading the labs. Based on what we heard from the TA's, they feel that the labs are disorganized. They found it difficult to clear up what they found confusing. The TA's are not given a formal training in the labs. If they don't meet enough with the professors or lab supervisor then they can get overwhelmed. That disconnection must be addressed. Scheduling meetings would help to solve that problem, but we think a formal training with the professors and lab supervisors would suffice.

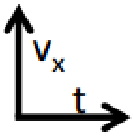
Work-Energy and Momentum

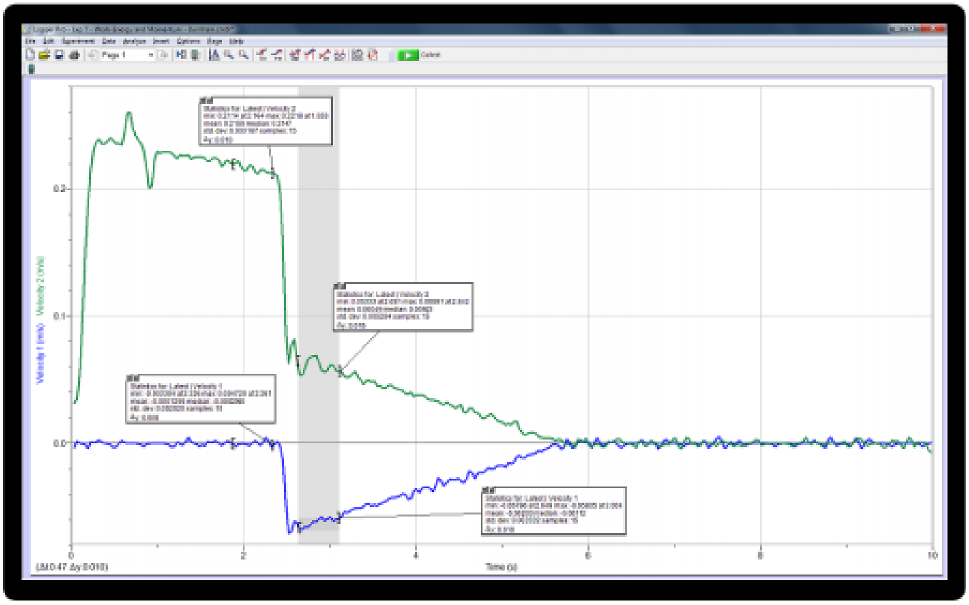
The Work-Energy and Momentum Lab focuses on observing the change in kinetic energy and momentum during elastic and inelastic collisions. To complete this lab, students are given a track on a level surface, two carts, and two motion sensors. One of the two carts has additional mass placed on top of it. Additionally, one cart has a plunger that protrudes from the bumper and can be extended or retracted. When the plunger is extended, the two carts will bounce off of one another.

Because both carts have a strip of Velcro attached to the bumper. When the bumper is retracted and the carts are allowed to collide, the Velcro strips will make the carts stick together. The carts also have magnets in them, to help the carts stick.



This lab, like many other experiments in this course, reveals too much information about the intended results to students. For instance, the last sentence of the procedure states, "you will have demonstrated that independent of the materials involved one entity (kinetic energy or momentum) is conserved (i.e. remains the same) during a collision, and the other one is not. The other entity will be very different depending on the kind of collision". The same problem exists in the worksheet. Question 6 states, "*In your own words*, discuss why the $\Delta K/K_i$ values are very different for the two experiments, yet the $\Delta P/P_i$ values remain approximately the same. Where does the "lost" energy go? How does work get done on the carts?" Finally, in the "overview" section of the procedure, students are provided a photograph of collected data. Screenshots of data should not be provided to students because it gives students something to measure their intermediate results against and defeats the purpose of the experiment.



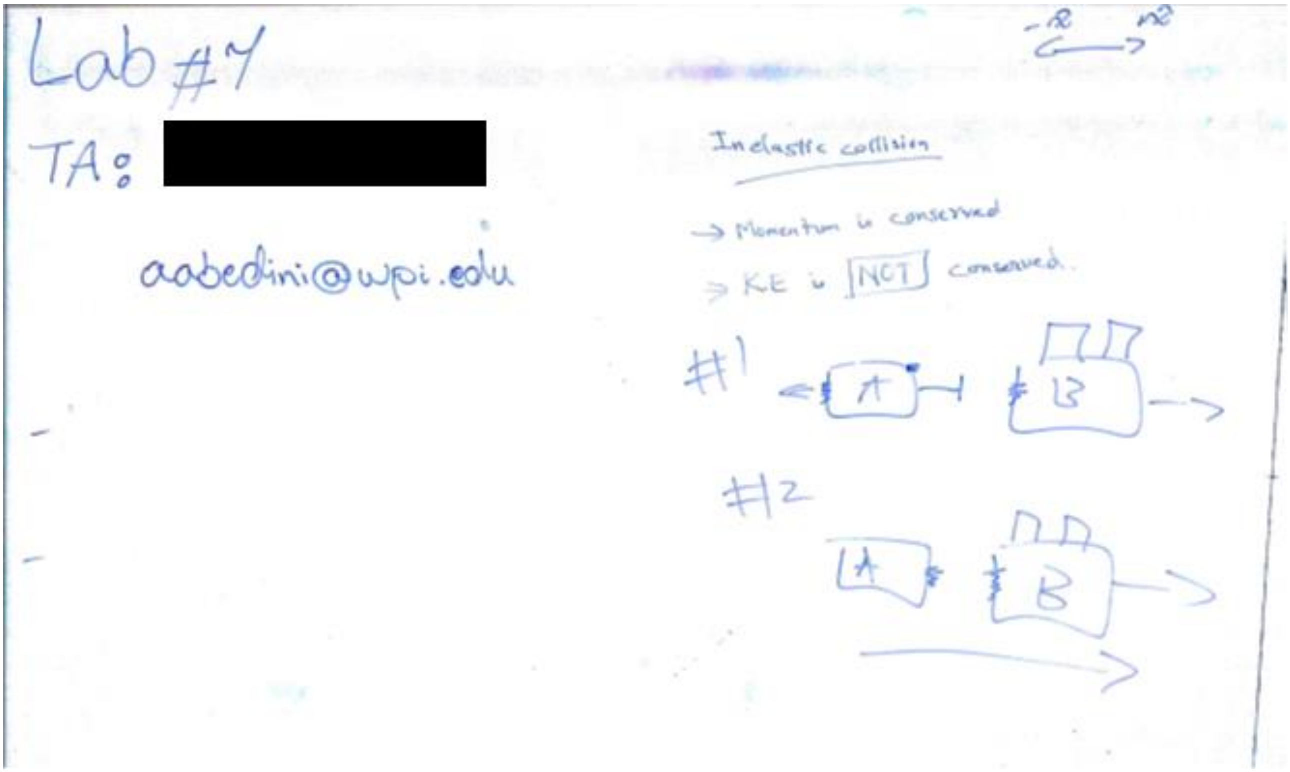


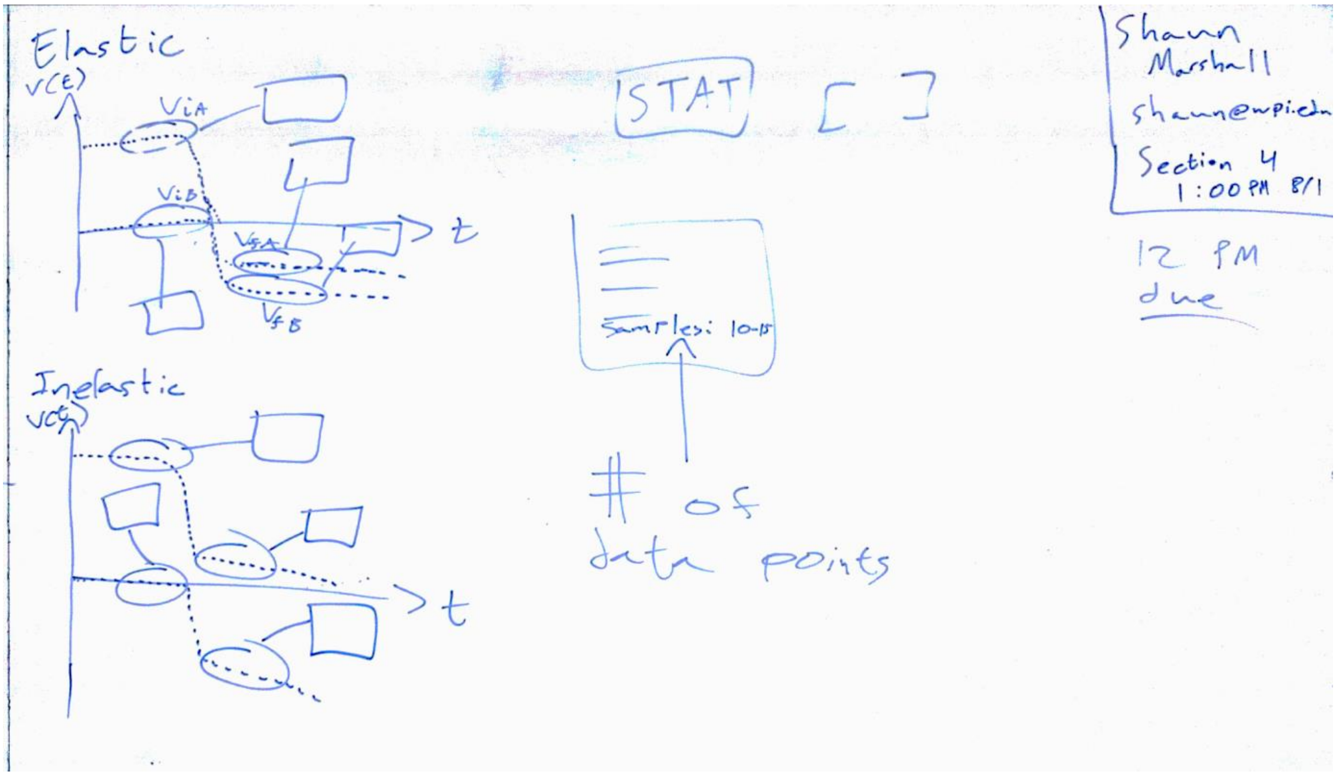
The major flaw with this lab is that students are told that one collision will result in conservation and the other should not – and are then told to verify that their results are in agreement. Instead, students should instead perform the experiment, and then use the results to draw their own conclusions about conservation.

There were also a few minor problems with the equipment during this experiment. For problem 4 of the worksheet, students are supposed to fill out a data table with collision data. One field in the data table is initial velocity. This is obtained by analyzing the data that is acquired through the use of the Logger Pro motion sensors. Since the sensors are not perfect, Logger Pro will detect a small initial velocity even though Cart B is completely stationary. The TA warned students to ignore this inaccuracy and enter 0 m/s into the data table instead. However, while it is true that Cart B is visibly stationary, students should not be encouraged to alter the data that the motion sensors produces because these small inaccuracies are inherently present in all values measured with the motion sensor. Altering only some of the data introduces more inaccuracy than it fixes.

Additionally, two groups seemed to have difficulty determining which portions of their data was useful. These students were selecting the meaningless noise at the beginning and end of their results in addition to their actual data. Including this meaningless data caused some students to have slightly skewed values when using any of Logger Pro's analysis tools. In Lab #0 (or any early lab in the course where there is extra time), it may help to put a greater emphasis on teaching students how to decide if data is relevant or not.

The Work-Energy and Momentum lab is an extremely educational lab and provides students with a real understanding of the underlying physics during a collision of two objects. However, the educational value of the lab is greatly diminished because students are not forced to conduct a traditional experiment. Instead, they are provided the intended results, and merely told to verify that their data matches the pre-provided conclusion.





Conservation of Energy

This lab focuses on conservation of energy in a spring mass system. The students set up a hanging spring mass system over a motion sensor to measure the change in potential and kinetic energy. The total mechanical energy, the sum of potential and kinetic energy, should not change throughout the oscillation. This experiment ran smoothly there were no problems with the procedure. This lab only had a few minor issues, mainly related to Logger Pro.

This is the 6th lab session the students attend. At this point they should be familiar enough with Logger Pro to the point that the software doesn't cause any major setbacks. Yet issues with the software still slowed the students down. First the students had trouble zeroing the motion sensor. After completing the experiment the students had a hard time creating a trend-line on their graph. If the students did not record enough data points then they couldn't create a trend-line using those points. One TA had to stop the lab to announce how to make a trend-line to the whole lab section. While the TA helped clarify this issue for the students, stopping the lab took a significant amount of time. Time is so precious to each of these labs, so losing time to a simple clarification issue is not ideal. Logger Pro has brought up clarification issues before, but after 4 labs the software should not slow the students down anymore.

The lab instructions created a few problems in this lab section as well. There is a point where the instructions are a little to vague. After the students set up the mass on the spring the instructions state to, “pull (the mass) down from equilibrium by just a few centimeters”. However, if the students pull the mass just a little too far, then the system oscillates too fast for the sensor to accurately collect data. In this case “just a few centimeters” is too vague. If the students pulled the mass about 5 centimeters instead of say 3, then their data will be inaccurate. Clarifying that pulling the mass too far can create error is worth including in the instructions.

The conclusion of this set of lab instructions was also flawed. The lab instructions end by giving away a core concept to the students. The last sentence of the instructions reads, “If all has gone well today, you have confirmed that mechanical energy is conserved for a mass on a spring”. This lab is set up for the students to prove that mechanical energy is conserved; it becomes much easier to prove if the instructions give away the conclusion. The point of this lab is for the students to use the experimental procedure to draw their own conclusion. In this case the lab instructions reveal that energy is conserved, but the students shouldn’t know that yet. If the students knew that energy is conserved before the experimental process, then what are they working toward? The first sentence of the instructions reads, “You have likely heard that ‘energy is conserved.’ This lab explores whether or not that is actually true.”

The students are not exploring the truth to this law if the correct conclusion is given to them. The students should conduct an experiment and analyze data to reach their own conclusion. We suggest omitting the last sentence

The Mass-Dependence of Friction

The Mass Dependence of Friction lab features an experiment with a cart on a track. The students are told to measure the mass of the cart on a balance and place the cart on a downward sloping track. A string is run through a pulley at the top of the track. The cart is attached to one end of the string, and a mass hanger is attached to the other. By adjusting the amount of mass on the hanger, the rate at which the cart moves down the track can be adjusted. Using Logger Pro and a motion sensor, students measure the acceleration of the cart as it moves down the track. Before coming to lab, students draw force diagrams for the cart on the track. This diagram is then used to find net force. Then, they set up the force equation, $F=ma$, to calculate the friction coefficient μ. Lastly, the students repeat that same procedure but with a larger hanging mass so that the cart accelerates up the track.

The first problem with the instructions is that the students were instructed to read through Part 1 but only one group had done so. Part 1 of the instructions is about creating a force diagram for the cart to determine net force. Students were supposed to come into the lab with a force diagram already done, but many of them did not. In fact, so many students were not prepared with a force diagram that the TA had to draw one on the board, which was a time consuming process. The TA should not have appeased the students with a force diagram. It is on the students to draw the force diagram themselves, if they are having trouble they can ask for assistance. The instructions state that part 1 should be completed before coming to lab and that any questions regarding it should be addressed at the beginning of the lab period. We suggest making pre-reading labs ahead of time more of a priority. In doing so, students would be better able to complete the experiment within the allotted 50 minutes.

By now the students are familiar with the Logger Pro software and therefore there were fewer questions about how to use the software. Students use Logger Pro to create a velocity vs. time graph, with which they derive the acceleration of the cart. Students are also asked to find standard deviation of their graph and present the data in their worksheet. The Logger Pro software is good for this lab because it does not do too much for the students; it only presents raw data that the students need to interpret on their own. The instructions also do a good job of clarifying what Logger Pro does to find the standard deviation so the students understand how it is found instead of being presented a number without context.

This lab is time consuming, but the experiment is worth it. We think this lab was one of the better labs. It touches on some important lessons -- such as drawing a force diagram, setting up and running a successful experiment, collecting data, and analyzing that data. The experiment is very effective at demonstrating the forces acting on the cart as it moves along a track. The worksheet also does a good job evaluating if the students ran a successful experiment and analyzed the data correctly. The instructions were also informative and easy to follow.

The Rigid Pendulum

This lab explores the period of a physical pendulum. The students start the experiment by weighing a meter stick. The meter stick is then hung from a hook so that it acts as a physical pendulum. Then the students record the period of the pendulum, after recording the mass, length (1 meter), and angle. After gathering experimental data, the students complete computations to discover the period equation for a physical pendulum as it relates to the pendulums moment of inertia. Since the experiment is so simple this lab didn't experience any significant setbacks. However, there were a few minor issues that are worth mentioning.

The equipment for this lab was slightly unsatisfactory. This lab calls for the students to measure the period of the pendulum, but they are not given stopwatches. Most students had their smart-phone with them, which they used to record. The Physics department should supply the students with the equipment to complete the experiment it shouldn't be on the students. It may seem insignificant but what if a group of students didn't bring their phones? It cannot be assumed that the students will be prepared with their own stopwatch. We suggest supplying the students with stopwatches for this lab.

Another problem in this lab was that the students were taking inaccurate measurements of the pendulum's period. The students were trying to start their timers as another student let go of the meter stick to start the period measurement. Attempting to start the timer as the pendulum starts its oscillation creates unnecessary error. It is much easier to start the timer and then observe the time at which the pendulum starts its motion. This suggestion should be added to the lab instructions to clarify the best way to measure period for the students.

The Electric Field

The electric field laboratory is the first laboratory in the PH-1120 and PH-1121 classes. While the intent of the laboratory is to familiarize students with the electric field, students are not given any experiment to conduct. Instead, students are given a worksheet and told to submit when finished. Therefore, there is a missed opportunity to conduct an actual experiment and teach students about electric fields.

At the beginning of the lab section, the TA polled the class and asked how many students had taken PH-1110 or PH-1111. Approximately three quarters of the class (26 students) had previously taken a physics course at WPI. As a result, most students were familiar with the lab submission process and the have also used the logger software.

There were no instructions included with the data sheet. In order to show students how to complete the do so, the TA needed to do an example problem on the board. However, the biggest problem with the assignment is that it teaches students about electric field as if an electric field only exists in two dimensions. In reality, by contrast, electric fields exist in all three dimensions – and the lesson should be adjusted to teach students about electric fields in a more realistic way.

Upon opening the lab questions, two groups noted that they were unable to make changes to the lab report. The TAs explained that before students can edit the file, they need to click "checkout". This is more of a difficulty with Microsoft Word, but enough students had trouble with it that we felt it deserved mentioning.

Two lab groups had difficulty with the question three on the lab report:

Determine the length and angular orientation of the electric field at the indicated point resulting from the given 3-charge superposition.

Firstly, the question should be reworded. ‘Length’ is not an appropriate term to describe an electric field. This question shows a field with three charges and asks students to calculate the net field. To help students with this question, the TA showed another example on the board. The correct approach is to apply Coulombs law, separate the charges into their components, and sum the results. This seemed to answer the student questions, but we were surprised that there was so much difficulty with this calculation.

The Electric Field and Field Lines

The Electric Field and Field Lines laboratory focuses on familiarizing students with drawing electric field lines. We immediately noticed that there are no instructions in this lab, and there is no experiment to complete. Students were simply given a "datasheet" (attached below) and a worksheet to fill out. We thought that this was an inappropriate use of the lab period. Physics labs present a unique opportunity to conduct an experiment that students may otherwise not be able to do themselves. Simply giving students a worksheet to fill out defeats the purpose of the structured lab meetings.

This lab, like the previous, also attempts to portray the electric field as a two dimensional effect. For the sake of accuracy, the lab should make some attempt to make it clear to students that the electric field operates in all three dimensions.

We noticed that three or four students left the lab about ten minutes into the hour, and about half had left by 25 minutes past. Very few students felt a need to attend the full length of the lab.

Determining Resistance

In the *Determining Resistance* laboratory, students are instructed to create a simple circuit consisting of one resistor and then observe the voltage drop across the resistor. Students are provided an ammeter, voltmeter, a circuit board, and an assortment of wires and resistors. This lab functions as an introduction to circuit wiring and Logger Pro

In order to collect all of the data in the provided 50 minutes, students need to work quickly. The TAs were very busy throughout the lab period, and spent the first twenty minutes helping students set up their circuits. While TA intervention certainly made it possible for many groups to finish on time, we are worried that too much intervention will make students dependent on the TAs. When students are forced to set up the circuit themselves, they learn a great deal more about how it works. We are concerned that students are missing out on an excellent learning opportunity. It is critical that students learn how these circuits work because later labs (Lab 5 in particular) require much more complicated wiring and there is simply not enough time for the TAs to help every group. We think that the first two labs should be combined (or simply removed), and that this time should instead be used to help familiarize students with circuit diagrams and wiring.

Despite the simplicity of the circuit, nearly every group had difficulty setting it up correctly. We suspect that this is many students' first time working with circuit diagrams.

Additionally, this is the first electricity and magnetism lab that requires students to collect data with Logger Pro. While most of the class had previously used the software in PH-1110 or PH-1111, most students were not familiar with the sensors used in this lab.

Students were told to first set up their circuit in accordance with the diagram in the instructions, and then verify with a TA that their wiring is correct. While this approach certainly helped students complete the lab on time, it resulted in a lot of “hand holding” and we are concerned that students will need to rely on the TAs too much in later labs when the circuits become more complicated. In addition, we overheard the lead TA tell the assistant TA that he had set a group's circuit up incorrectly. This was concerning to see, but it is clear proof that having both an assistant and lead TA in labs is an effective strategy.

One group's power supply broke and needed to be replaced for them to continue. We were not able to determine if the failure was a result of improper use of the equipment or if the power supply failed on its own. However, this was the group that the TA had incorrectly help set up.

Two groups helped one another with Logger Pro. This collaboration was nice to see, and allowed the TAs to help other groups. Especially given WPI's emphasis on group collaboration, we think that this teamwork should be encouraged more.

The instructions state that students are to connect the wires to “the designated resistor R3, R4, R5, or R6” however the TA’s told the students to choose either the 51 Ohm resistor or the 68 Ohm resistor.

Students are asked to report their results in standard form. We observed that four groups had difficulty with doing so. The TAs recommended that students watch the video that is linked in the PH-1110 Lab 0 instructions. Many students followed this advice, but two groups commented that the video will only load in Internet Explorer (and not Google Chrome).

Four groups were still working when lab time expired.

Electric Potential and RC Discharge

The electric potential and RC discharge lab focuses on familiarizing students with the property of "potential difference".

In this lab, students are given a circuit board and some capacitors and are asked to observe the capacitors discharging when the voltage is disconnected. Students are asked to connect a varying number of capacitors in different arrangements:

1. C1
2. C2
3. C1 and C2 in series
4. C1 and C2 in parallel

While the TAs were eager to help students get set up, they were doing too much of the work. We watched on a few separate occasions where the TA rewired the students' entire board while the students watched.

The instructions tell students, "As soon as you disconnect the + voltage, the capacitor will begin to discharge through the resistor, and you will see the two voltage graphs being recorded suddenly change profiles- one following an exponential profile with time, while the other follows a downward-sloped straight line". There are a few problems with this statement:

1. It makes the lab unexciting
2. There is no "experiment" if students are given the answer
3. Students should draw a conclusion from their data, not the other way around

The lab report sheet suffered from the same problem:

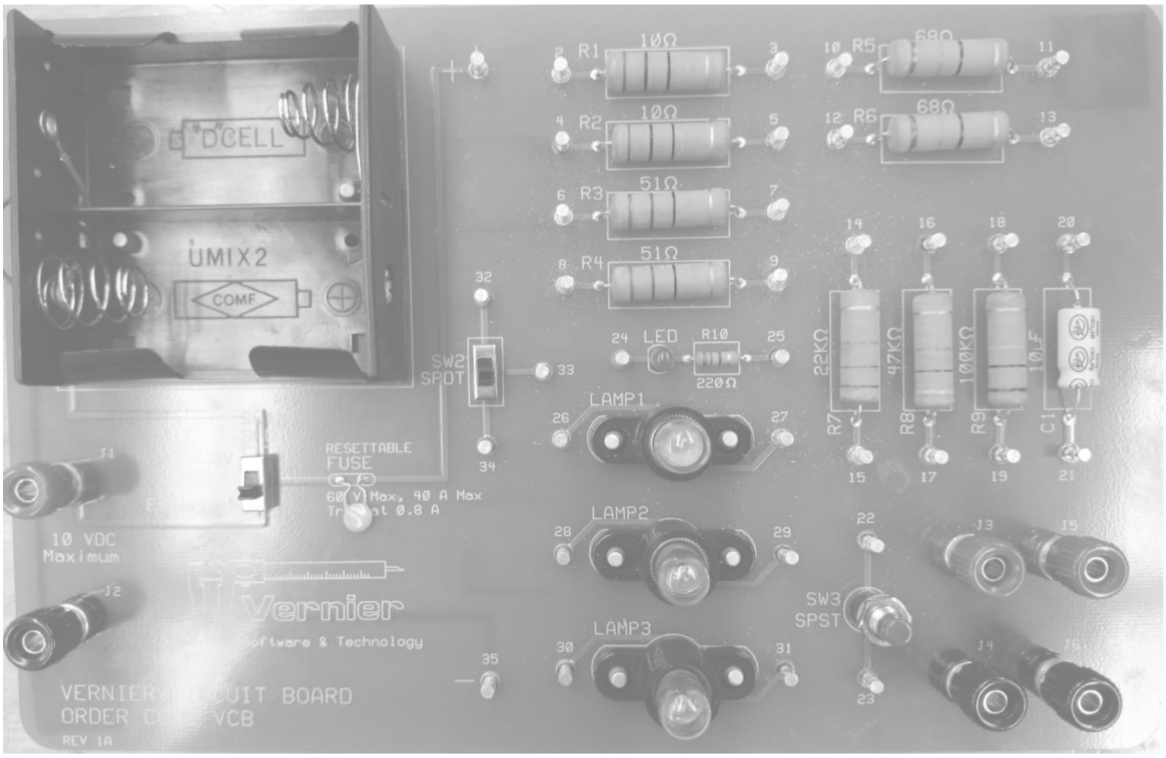
> "Now calculate the parallel and series capacitance based on slope values and compare those results to values calculated from the slope values of the individual capacitors. **Are your measured parallel and series capacitances equivalent to your calculated values, taking uncertainty into account? With any luck, they should be!!!**"

Additionally, the first four questions of the lab report deal with the same concept. Adding some variety to the questions and asking students to analyze their findings in the lab report would be more beneficial. These questions, although related to potential difference, ask students to calculate how far away two plates of a capacitor should be in order to have a specified potential difference. Since this was not a focus of the lab, these questions seem out of place. Below is an example question from the lab report:

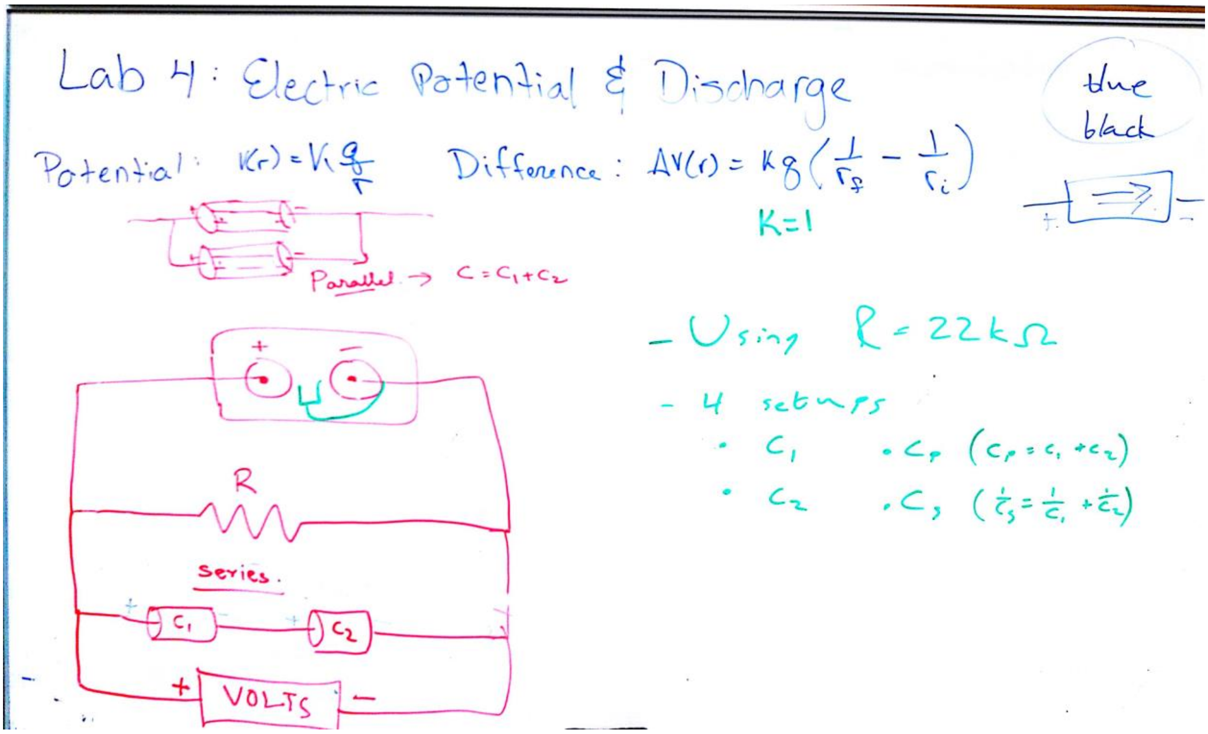
1. Using a single point charge of –2, indicate where (how many grid units away) you would place initial and final points in order to have a potential difference of –3 V. [Note: $\Delta V = -\left(\frac{U_b}{q_0} - \frac{U_a}{q_0}\right) = q\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$, begin at page p761and continue through p 770, 13th edition Young & Freedman and remember that k=1 for our purposes.]

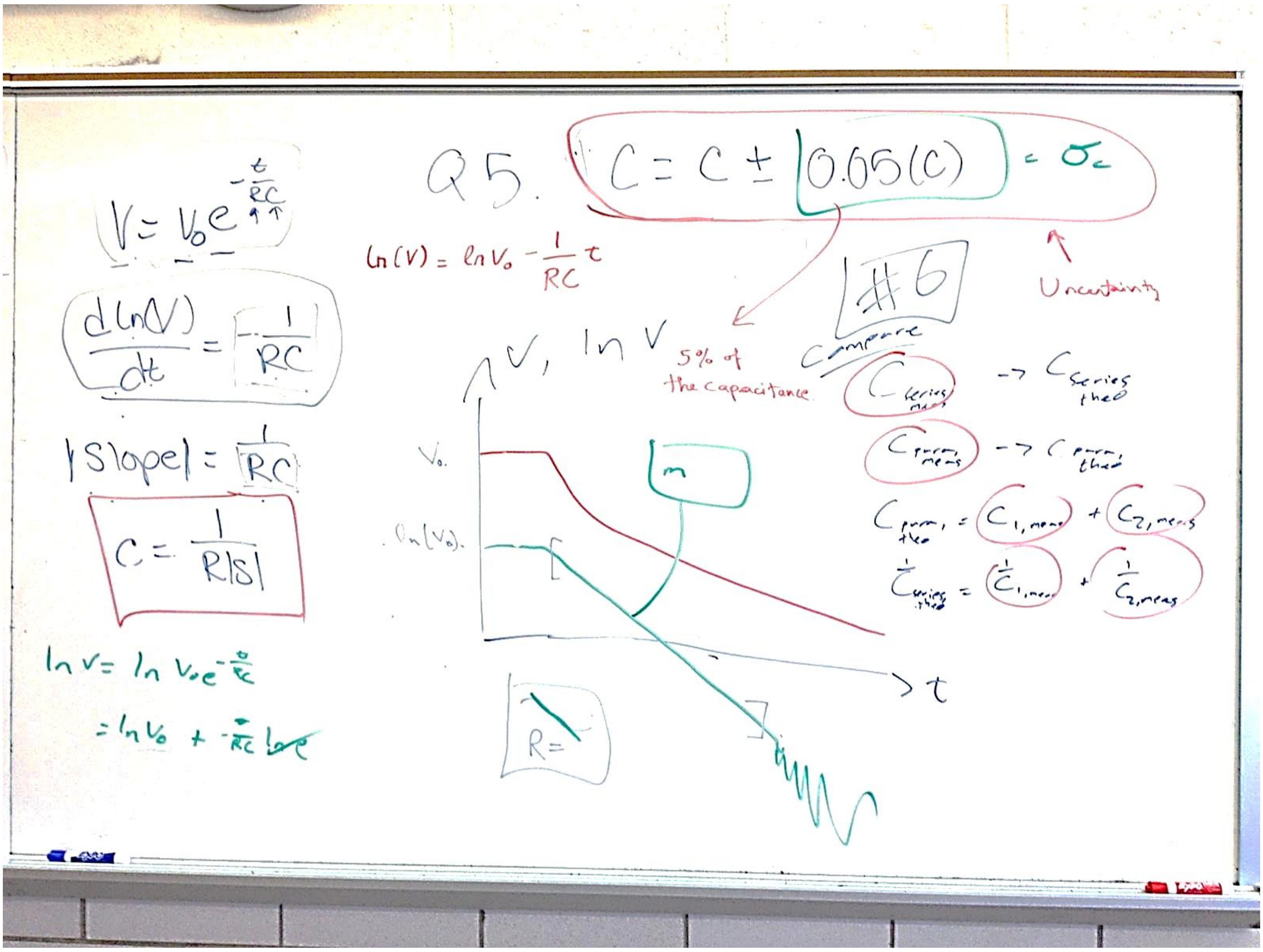
In addition, the worksheet tells students to report their results in an "industry standard form". However, this statement is misleading because there is no "industry standard" for reporting data. It is important for students to know how to report their results – but it is equally important not to mislead them into thinking that there is only one "correct" way to present the data.

In all, this lab operated smoothly – but only because the TAs did not give students a chance to make mistakes or complete the lab themselves. In order for students to learn and benefit from the lab sessions, it is critical that the TAs allow students to make their own observations and analyze their own data.



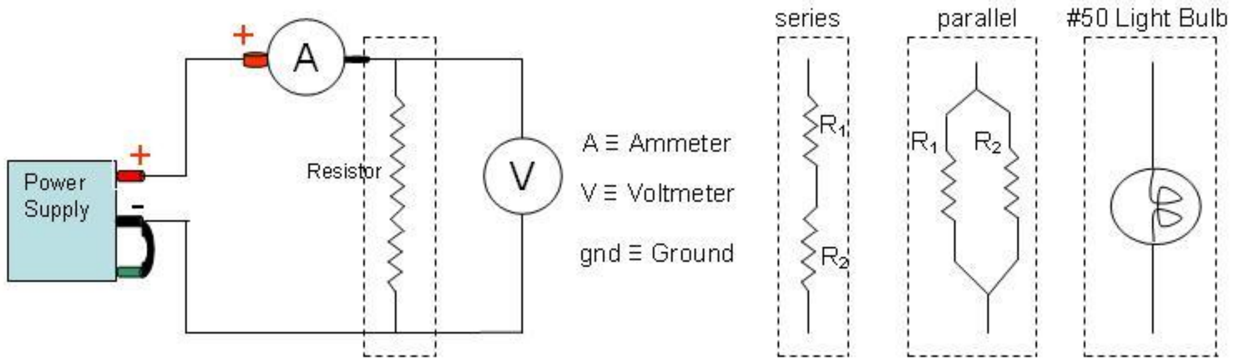
1A photograph of the circuit board that students are provided.




Q5.
C = C ± 0.05(C) = σc
Uncertainty
5% of the capacitance
V = V0 e^(-t/RC)
ln(V) = ln V0 - (1/RC) t
d ln(V)/dt = -1/RC
|slope| = 1/RC
C = 1/(R|S|)
ln V = ln V0 e^(-t/RC)
= ln V0 + -t/RC
V, ln V
V0
ln(V0)
m
t
R=
#6
Compare
C series meas -> C series theo
C parra, meas -> C parra, theo
C parra, theo = C1, meas + C2, meas
1/C series theo = 1/C1, meas + 1/C2, meas

Resistors and Light Bulbs

The Resistor and Light Bulb Experiment serves to familiarize students with the behaviors of both linear and nonlinear resistors. To complete this experiment, students are provided with an assortment of resistors – a 58 ohm resistor, a 68 ohm resistor, and a light bulb. With these resistors, students are asked to construct a simple circuit (similar to the one created in Lab 3) and measure the values of the resistors in both series and parallel arrangements.



2- The circuit diagram for this lab

The most evident problem with this lab is that the conclusions of Part I and Part II are provided for students within the instructions. Ideally, students should be making these observations themselves. The beginning of Part II states, "As you have seen, the carbon resistor is AMAZINGLY linear (constant resistance value independent of the voltage).So are ALL resistors of constant resistance value? Absolutely not!" Additionally, the end of the instructions state, "Now you have seen two wildly different examples of resistors – the extremely linear carbon resistor and the extremely nonlinear light bulb – and you have finished the data-collection portion of this experiment". This problem persists within the worksheet questions as well. In question 2 of the worksheet is the statement, "If you made the measurements in a reasonably careful and consistent fashion, you should find that the MEASURED and CALCULATED values of R_S, each complete with uncertainty, should OVERLAP (or NEARLY so, to within a factor of 2 times the individual resistance uncertainty – or less) in resistance values. Do they?!" Explicitly providing this information not only defeats the purpose of the experiment, but it also removes the opportunity for students to practice developing and testing a hypothesis. Furthermore, there is no purpose for students to collect this data if they are not required to analyze it themselves.

Additionally, there are some issues with the procedure. In order to collect data, students are told to incrementally increase the voltage of the power supply and collect current vs voltage measurements within logger pro. In order to calculate the resistances, the instructions tell students to use the “tangent function” within logger pro. When using this tool, Logger Pro shows a (tangent) slope line at each point. Students are told to record this resistance value. Although the tangent function is a useful feature of logger pro, it should be avoided since it extrapolates data on either side of the point in order to generate a tangent line. Not only are students not warned about this behavior, but the only documentation that students are provided about this function is irrelevant. In the instructions, the words “tangent function” link to an almost completely blank page except for the text,

> “Now move the cursor into the x vs. t field, left-click the mouse there to select it, and then left-click the “M=” button up on the tool bar in order to obtain a slope-measuring tangent line on the x vs. t graph. Move the cursor around in the x vs. t field and note that the slope-value at a point on the x vs. t graph is identical to the corresponding v_x-value on the graph below (as it should be, of course!).”

This information refers to the instructions of an 1110 lab and are completely disconnected from this experiment.

Another issue with this lab is the lack of professionalism within the instructions. For instance, in question 3 of the worksheet, students are told that if their measured and calculated values of the resistors in series do not overlap, then “please show your work to your lab instructor – something has evidently gone horribly wrong”. This tone is carried throughout most of the lab instructions and should be revised to be more formal and less disparaging.

Moreover, this lab does not include any problem-solving suggestions within the instructions.

Because this is most students' third time working with circuits, many are still unfamiliar with following circuit diagrams and constructing the required circuits. It would help tremendously to include a few short sentences on how to confirm that everything has been set up correctly. This way, students do not need to rely on the TAs to verify correctness, and therefore, the TAs will be able to spend a greater amount of the lab time helping students with other areas of the lab.

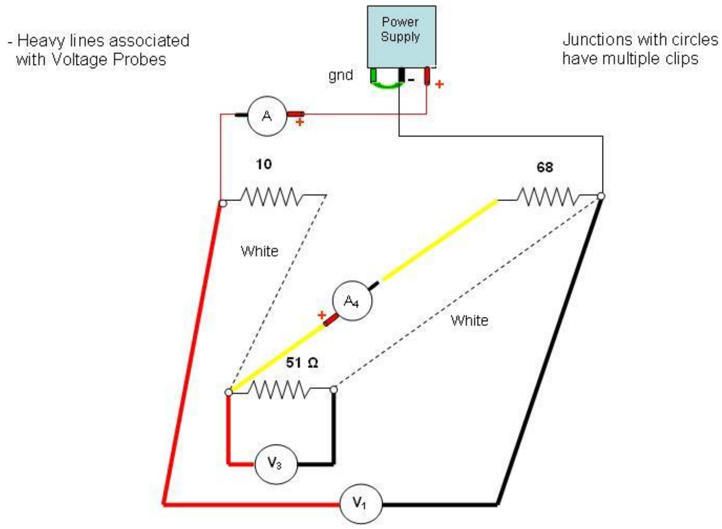
Finally, this lab's instructions, like other PH-1120 and PH-1121 lab instructions, directs students to report findings in an "industry-standard" format. Students should be made aware that there is no such "industry-standard" when reporting results and that such a statement is vague and misleading.

Linear vs. Nonlinear Circuits & Magnetic Field Measurements

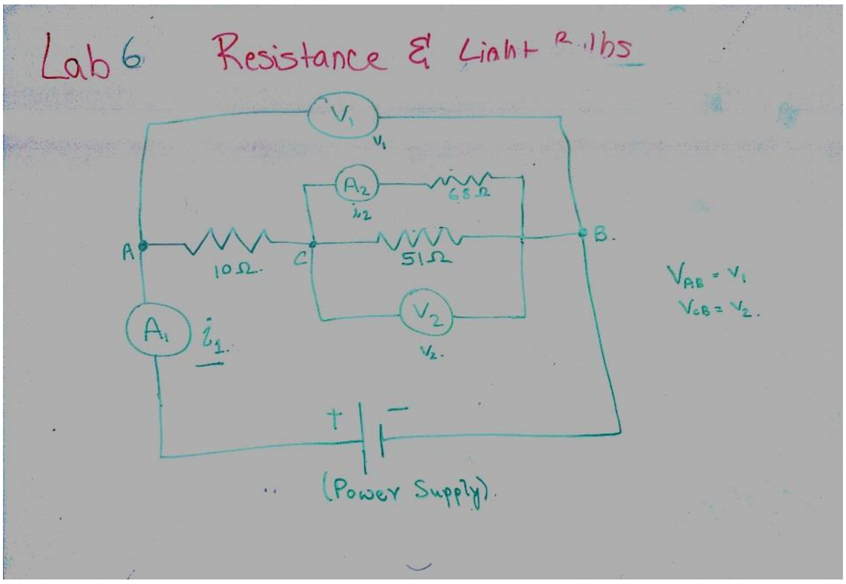
The Linear vs. Non Linear Circuit & Magnetic Field Measurements laboratory contains two different experiments. The first experiment attempts to further familiarize students with circuit diagrams, reinforce the students' knowledge about nonlinear and linear resistors, and teach students how to calculate current, voltage, and resistance across a variety of linear and non-linear resistors. The second experiment within this lab requires students to use a hall-effect probe to study magnetic fields. While both of these experiments are worthwhile, there were a variety of problems with the lab instructions and way that the TAs managed the lab.

Students spent the majority of the available lab time constructing the circuit that is used in the first experiment. Compared to the circuits in previous labs, this circuit was much more complicated to assemble. In most lab 6 sections, the students were instructed to verify with either the lead or assistant TA that the circuit was constructed properly. If the circuit was improperly setup, the TA typically made the necessary adjustments and instructed the students that they could begin collecting data. This not only destroyed the educational value of the lab (since many students did not get a chance to set up the circuit themselves), but many groups sat idly and wasted time as they waited for the TA to check their circuit. One section, however, took a much more educational and effective approach to this problem. Rather than having students check their circuits with the TA, the TA told students how to check the circuit themselves. He told students to open Logger Pro and verify that the ammeter and voltmeters were reporting appropriate, non-zero values. While the TA still answered student questions about the circuit, he interfered much less than other TAs and allowed the majority of students to construct the circuit by themselves. Even though there was no assistant TA present, students in this section, on average, had completed as much (if not more) than sections that used the normal procedure for checking the correctness of the circuit. This approach seemed to be much more effective and taught students valuable debugging skills.

Additionally, the difficulties that students experienced while attempting to build the circuit was only compounded by the messy circuit diagram that was included in the lab instructions. In order to alleviate this problem, the TAs sketched a much clearer diagram of the same circuit on the whiteboard at the front of the room.



The circuit diagram included in the instructions



The circuit diagram that was drawn on the board by the TAs

In one lab section in particular, two groups were unable to get the circuit properly constructed at all. After having spent over half an hour trying to get the circuit built, these groups asked the TA for assistance. The TA was also unable to get the circuit working and attributed the difficulties to malfunctioning sensor equipment. Because these groups were unable to collect any data for this portion of the experiment, the TA asked a group that had successfully collected data to email their findings to the groups that experienced problems. During the time that the TA spent helping these students, only the assistant TA was available to help answer questions from students. At the end of the lab, less than half of the class had fully finished conducting the experiment.

This lab instructions also suffered from problems with organization. The overview sections of the lab instructions, which is typically used to provide students a brief description of what the experiment entails, provided students with important details about the magnetic field portion of the lab. The overview reads,

> "All that you need to know about the Hall Effect probe is that it contains a thin, flat wafer of a semiconductor material and is sensitive to the DIRECTION of the magnetic field as well as its MAGNITUDE. The wafer is mounted about 1 cm back from the tip of the probe with its SURFACE-NORMAL parallel to the long axis of the probe. This results in the probe reading the greatest magnetic field strength (magnitude) when the magnetic field is parallel (or anti-parallel) with the long axis of the probe. This further means that the probe measures zero field strength when the magnetic field direction is PERPENDICULAR to the long axis of the probe"

These details are useful for students and should be moved to "Part II" of the lab instructions. They do not belong in the overview of the lab.

There are also a variety of issues with the clarity of the instructions. In Part II, students are instructed to "bring the magnet back again, and repeat this cycle several times while watching the probe reading. **Reverse the direction of the bar magnet, and repeat steps 6 and 7**." These instructions were especially confusing for students because there are no numbered steps present anywhere in the lab instructions. In addition, the instructions say, "With the magnetic field probe **held in place on the surface of the lab bench**, zero the reading, and then begin collecting data". The phrasing of this statement is misleading because students do not use anything to hold the probe in place. Finally, students were frequently mislead by the length of Part II's instructions, which spans multiple paragraphs. Despite its length, however, this portion of the lab only takes about ten minutes to complete. As a result, many students experienced difficulty managing their time within lab and rushed through Part I to get to Part II. In any section, only about a quarter of students seemed to be able to fully complete both parts of the lab. By revising these sections of the instructions, the clarity of the instructions could be greatly improved and students should be able to complete the lab in a much more timely manner.

It also became apparent that some student groups did not fully unwire their circuit before leaving the lab at the end of the allocated time. As a result, one group of students in the next section only needed to construct half of the circuit. The TAs should be very explicit in reminding students to completely unwire their circuits at the end of the lab section.

Finally, the worksheet tells students to “Report your least-squares fit values for both the equivalent circuit resistance and R^{68} in industry-standard form (uncertainty rounded to one digit, unless that digit is one, in which case round the uncertainty to two digits; the main value then rounded to the same place value as the uncertainty). This statement is misleading – because *there is no* “industry-standard” for reporting results.

While this lab was effective in teaching students about magnetic fields and current and voltage values across a variety of resistors, the complexity of the instructions and the generally poor management of the lab by the TAs hindered its educational value. By splitting this lab into 2 labs, clarifying the lab instructions in the appropriate places, encouraging students to debug their own circuits, and teaching students how to manage their time throughout the lab, this experiment could be much more successful.

The Magnetic Field

The Magnetic Field laboratory features a magnetic field probe that is inserted into a 400-turn coil, or solenoid, and reads the magnetic field created when a current is run through the coils. This reading is performed in two solenoids with their bores aligned. After the first reading the students turn the second solenoid around 180 degrees and perform the same reading. Next the students take away one solenoid and place it far away from the other so that it does not affect the magnetic field reading. Then the students perform a data collection on one solenoid while varying the current being run through the wire. While performing the experiments the students fill out a downloaded data sheet with their values for magnetic field. After the experiment is complete there is a worksheet to fill out.

Each lab is used to give the students a hands on lesson on a topic covered in class, this lab was on magnetic field. Why then is there a short magnetic field experiment in the Lab 6 section when Lab 6 covers linear vs. nonlinear circuits? That magnetic field experiment makes much more sense in this lab since Lab 6 took the students a long time to complete and most groups didn't even get to the magnetic field experiment during lab time. On the contrary this lab took the student much less time to complete. The first group finished the experiment after 20 minutes and every group finished before lab time was up. The magnetic field experiment from Lab 6 fits into Lab 7 much better. Alec and I both thought the experiment performed on this lab was effective. The equipment worked without any bugs. We thought that seeing the change in magnetic field as the students moved the probe was effective in demonstrating the behavior of magnetic field to the students. That being said the assessment of the student's knowledge of magnetic field was poor. The data sheet asks for the reading of max magnetic field for each current value used in the single solenoid experiment. This requires the students to look at a number on a graph and then type that number into a document. The worksheet has three questions the first is to compare those maximum field values. The second asks for a theoretical field value given the number of turns in the coil and the length of the solenoid. The students could measure the length themselves. An equation to solve for length is given to the students by the TA's. After the students find theoretical magnetic field, the last question is to find the standard deviation between the calculated and measured values. The students are never asked to assess the first experiment at all; they could have been asked a question on how the orientation of the field changes when one solenoid is turned 180 degrees. The students are not challenged at all by this lab; their knowledge of magnetic field is not tested. The only knowledge they are tested on is their ability to read numbers off a graph and ability to plug numbers into a few equations to come up with a solution.

Our suggestions for this lab would be to add the second experiment from Lab 6 into this lab. For time constraint issues it just makes more sense for that experiment to be in this lab. We also scrapping the data sheet and worksheet and writing new ones from scratch. This worksheet was simple; we think the worksheet should be a little more challenging and the data sheet can be omitted. The experiment in this lab was very good but we think the worksheet questions could have been made much better.

Electromagnetic Induction

This lab serves to increase student understanding of magnetic fields. In the first part of the experiment, students use a magnetic field probe to measure the magnitude and direction of the Earth's magnetic field. In the second part of the experiment, students use a differential voltage probe to measure the changes in voltage as a magnet passes through a coil.

Students begin the lab experiment by using the magnetic field probe to calculate the magnitude and direction of the Earth's magnetic field. After collecting data, students are told to verify that their measured field strength is in the vicinity of 0.5 gauss. Ideally, this should be rephrased. Students should be told that the Earth's magnetic field is approximately 0.5 gauss, but it should be up to the students to determine what analysis is necessary for a properly conducted experiment.

Once students finish the first part of the experiment, they move onto part II, which tasks them with measuring the changes in voltage as a magnet is passed through a coil. These instructions tell students to “Place the blue foam circular pad on the bench, flat side up, and place the coil on that top flat surface with the central hole of the coil facing up.” This statement is hard to follow and should be revised for clarity. Something like, “Place the circular blue foam pad on the bench with the flat side facing up. Then, place the coil on top of the foam pad with the coil’s central hole facing upwards” is much clearer.

Later in the instructions for part II, the students are told to, “Click the ‘Collect’ button to start the voltage recording, and then slide the bar magnet at your station rapidly into the central hole of the wire coil. **You should see a voltage spike appear on the recording.”** This last sentence should be removed. Furthermore, the instructions say, “**In general, the faster you slide the rod in or out, the bigger the induced EMF will be. As you slow down, however, you will reach a point where you will see no effect from the changing magnetic field – It’s changing at just too slow a rate**”. The previous statements, this observation should be made by the students, rather than provided to students within the instructions.

Next, it says, “Now turn over the magnet end for end, and repeat the previous two bullet points, **noting that the polarities of the voltage spikes are opposite from before. (Why?)**” Firstly, polarity is not the correct term to describe the appearance of the graph. Magnets have polarity, graph spikes do not. More importantly, students should be able to observe that flipping the magnet upside down will cause the voltage spikes to flip from positive to negative and negative to positive.

In the second half of part two, students are told to study the areas under the voltage peaks on their graphs. To do this, students are instructed to click on the “Area” button within logger pro. Logger pro will then automatically provide students with the area under the peak. It may be beneficial to explain to students that logger pro achieves this by taking the integral of the peak. Furthermore, the lab instructions tell students what their observations should be. The procedure states, “**The area of the second peak should be opposite in sight, but similar, if not identical in**

magnitude to the area of the first peak." Students should make this observation by themselves.

Finally, the instructions state, "As a final test, one partner should grab the coil in one hand, turn the blue foam pad over, making sure that it is centered on the black rubber sheet at your station". Students are not provided with any rubber pad. The TAs made a note of this at the beginning of the section, but it would be best to remove this sentence from the procedure entirely to avoid confusion.

The most prominent issue with this lab is the amount of answers that the instructions provide students with. Because of this, students are given very little opportunity to make their own observations. Despite this, the worksheet questions are well put together. They ask students to analyze their findings and do a good job testing students' conceptual understanding of the physics. This lab has the potential to be very educational – but its value is diminished by the poorly designed instructions.

Survey Feedback

In order to better identify potential issues with the laboratories, all TAs for PH-1110 and PH-1111 were sent an anonymous survey. Below is a list of the questions that were asked, as well as the responses that we received.

- **Based on your observations, are labs being returned to students in a timely manner?**
    - I do my best to let students know as soon as the reports are graded. I also make a considerable effort to not get behind in my work. In general, I try to return labs before the next one, and if there is an upcoming exam, I will try to return labs even sooner.
    - This is hard to say since it depends greatly on the TA and their schedule. Most of the time I would say yes.
    - As far as my experience is concerned, yes.
    - Yes.
    - Some TA's return them early, some of them take a while

- **Can you think of any issues that you have witnessed or experienced with the lab equipment?**
    - In PH-1120 Lab 6, the circuit is complex and sometimes even if the circuit looks okay, it won't behave quite right. Additionally, if there are 4 or more probes plugged in at once, Logger Pro tends to misbehave.
    - The equipment often fails without notice, the computers randomly shut off occasionally and new TAs have now idea how to troubleshoot with the equipment.

- Especially during A- and B-term, there tends to be a shortage of equipment due to the large influx of new undergraduates. Many of the power supplies are defective as well.
- No.

- **Can you think of any issues that you have witnessed or experienced with MyWPI?**
  - Sometimes when students submit electronically, when we (the TAs) try to read submissions within MyWPI, non PDF files break formatting and hide text boxes with responses. I warn students that they should only be submitting PDF files, and yet students still do not.
  - Sometimes when students upload files, the file is blank even though they say it was the correct document. This does not matter if the document is a .pdf or a .doc.
  - Very frequently, the labs we have end up sourcing out to sharepoint or a professor's personal website. However, I'm not even convinced the professors take the time to make sure that the sourcing works so we end up with a multitude of students who can't gain permissions to view lab instructions. MyWPI also likes to conduct maintenance at the oddest of hours, sometimes even as early as 10AM. I understand there is nothing that we can do about that because it is a netOPs issue, but it is still a major inconvenience.
  - Some students have complained that the submission process is confusing. Additionally, some of the course materials only display properly in certain browsers, or (seemingly) at random times throughout the day.
  - A lot of times MyWPI goes down, there should be an alternative

- **Do you find that there is adequate support for any problems you encounter as a TA? (Is there someone you can go to for help?**
  - Yes. I have not encountered many problems, and I think that the chain of command is clear.
  - I think there is adequate support during parts of the day, however many of the new TAs don't know who the experienced TAs are.
  - Absolutely not. I find that most of the time the professors don't even bother looking at what lab assignment corresponds with that week's lecture (with the exception of professor Phillies). That being said, I've run into occasions where the lab material supersedes the lecture material and the students end up completely lost. Beyond that, it's pretty much up to us to figure out any issues.
  - Yes.
  - Yes. One lead and on backup can do the trick.
- **Do you feel that TAs are trained properly?**
  - No, I do not think that the TAs are trained properly. In PH-1110, the TAs show up the first day, are told to do a lab by themselves and present to the others. The session is more social than instructional. There is (as far as I am aware), no exact equivalent for PH-1120 or PH-1121.
  - Not at all. The TAs go over the PH 1110 labs and do not shadow an experienced TA. Many of the new TAs feel lost and overwhelmed.
  - It wouldn't be the worst idea to have the TA's conduct the labs themselves before they have to teach the labs. Many of us have done these labs but that was upwards of 4 or 5 years ago. Beyond that, there isn't that much training that can be done. It's a job where experience is your guiding principle.
  - Yes.
  - There should be more introductory training, like the session that Fred did.. Each TA represents one lab and everyone gets a gist of what they are going to be conducting with students.

- **Can you think of any issues that you have witnessed or experienced with the lab instructions?**
    - Students don't read the lab instructions. The best way to fix this is to ask them what the instruction say when they ask for help. As a TA, I intentionally avoid reading the instructions before coming to lab. While some may think that this is a bad idea, I find that learning the lab *with* the students allows me to better understand the questions that students have during lab.
    - Many of the lab instructions are wordy and thus confuse the students. Most of them have things for the students to do as practice before the actual lab. However many of the students will spend too much time on the practice part of the lab and not get to the actual lab.
    - In short, they are god awful. They are unclear, the spelling and grammar is atrocious, and many of procedures have changed over the years and the instructions never reflect this. We expect our students to put a lot of care and effort in their lab reports yet we can't even give them lab instructions that look someone spent more than 5 minutes preparing. I've even found that in a vast majority of lab instructions, it's not even clear what you're supposed to be calculating. It honestly looks as if someone contacted a local elementary school, had their students conduct a science fair where each student make a project based on what they thought was a neat science project, and we took all of those and said "Good enough". And then, after giving our students these lab instructions, we're expected to sit there and harshly critique their work. It seems rather hypocritical.
    - The lab instructions are poorly written in general. My suggestions for improvement are:
        - (a) numbered and/or bulleted steps, rather than paragraphs
        - (b) clearer diagrams/figures
        - (c) clearly stated lab objectives and expectations for the lab report.
    - If the department provided support for someone with technical writing experience (not just academic writing) to spend the time to redo them, I know several people who have said they would be willing to.
    - No.

- **Labs are typically structured so that there is a lead TA and an assistant TA present. Do you think that this strategy is effective? Why or why not?**
    - It is effective in some ways, and detrimental in others. On one hand, when one person is grading the section, there is less discrepancy. If one person is grading and wants something specific, if the other TA doesn't tell them to put that thing, the first TA may take points off. However, having a second person in the lab time is extremely helpful and definitely helps speed up the lab process.
    - I enjoy it, sometimes we get overburdened with questions so it's nice to have the extra help.
    - Yes because there are often a lot of questions during the labs. It also works well if the backup TA is new and the lead TA is experienced allowing the backup TA to see how it is taught and get a feel for issues before they are a lead TA.
    - Yes. It's useful to have two people, and it's good to have pre-decided who will give the lesson at the beginning.
    - Yes.
- **Are students typically able to complete labs on time? Do you have enough Time to prepare for lab?**
    - It generally depends on the lab. The 1110 labs tend to be timed well, however, not so much in 1120 or 1121.

    - No. Most of the students have a very hard time meeting the deadline and I often have to extend it for them. I think that if they were given more time the quality of the labs passed in would also be better. I don't think it helps them learn anything when they have to rush through the lab and worksheet.
    - In my experience, yes. I tend to be very lenient with the submission dates and times because of the quality of the lab instructions.
    - Yes and yes.
    - Yes.

- **Approximately how much time do you spend working on TA related activities per week? (Attending labs, grading, etc.)**
    - It is hard to put a number on it, but generally not too much time.
    - For 4 sections grading 2: ~17 hrs
    - ~20 hours a week.
    - Approximately 20 hours a week.
    - 15 hours a week.

- **Do you find the grading guidelines to be clear and comprehensive? How do you think the grading process might be improved?**
    - Honestly, I think the TAs should have their own grading guidelines and the grades should be normalized by section. All TAs grade differently -- which is fine -- as long as they're clear.
    - I think the grading process would improve a great deal if answer sheets and point values were given to TAs. That way grading is consistent and objective.
    - Since each lab is different, it's difficult to have one single set of clear, concise instructions. I think the ones we have are too general to give the students a good understanding of our expectations.
    - No. The grading guidelines generally penalize simple mistakes the most (proper format, sig figs, etc) but do not verify whether the student grasped the physical concept or put forth any effort toward understanding the purpose of the lab.
    - Yes, they are good.

- **What is your major?**
    - Physics
    - Physics
    - Physics
    - Physics
    - IT

- **Any additional comments?**
    - A lot can be improved. It is hard to rehash every lab. Some labs are disasters and some are better. I don’t think students will ever read the instructions. TAs should be able to penalize students for wasting their time.
    - I have taught these labs for 3 years and took them as an undergraduate.

Appendix

The forthcoming section is about individual labs. For each experiment, the procedure is included -- as well as any worksheets or data sheets that students were provided. Following this information is our analysis of the experiment. There are ten PH-1110 laboratories (#0 - 9), seven PH-1111 laboratories (#1-7), and eight PH-1120/PH-1121 laboratories (#1-8).

PH-1110 Laboratories

0. Expressing Uncertainties of Experimental Data

Procedure

Overview

The goal of this experiment is for you to learn how to express the results of your laboratory exercises. There is error in any measurement, even the most precise and accurate ones. The proper study of errors requires a whole course or two. While we do not aim to turn you into expert experimentalists in introductory physics courses, we do want you to know how to report a result of an experiment that reflects the possible error, or uncertainty, in it.

We will use a type of uncertainty called the sample standard deviation – or more simply, standard deviation. The formula for it is not important at the moment. What you need to know is that when a large number of measurements are taken, the measurements cluster around an average value, normally distributed in a bell-shaped curve. The standard deviation tells you that approximately 2/3 of the data lie within a range between the standard deviation subtracted from the average and the standard deviation added to the average.

Because we want to focus on expressing uncertainties in this "experiment", you will not use equipment other than a computer this time. You will enter numbers into a worksheet that will represent experimental data. There are two parts to the experiment. In the first, you will learn what we mean when we say "Express your result in standard form." In the second, you will learn about relative uncertainties.

Most results from your laboratory work in this course should be expressed in standard form. Sometimes you will be asked for a relative uncertainty. In contrast, in lectures, summary homework, and exams, you will report your answers in either exact form, e.g. ½, or to three significant digits, e.g. 0.500.

Now please open the worksheet and move on to Part I (links below).

Part I, Standard Form

• If you have not yet opened the worksheet at the link below, do so now. The columns of this Excel file accept numbers that you enter under the title "Numerical Values." The count of the number of entries is given under "Number," along with the "Average" of all entries and the "Standard Deviation", which is a measure of the amount of scatter among all the entry values, and will not provide a numerical value until you have entered at least two numbers into any column.

• In the example in Column A, the values are: 1, 3, 5, 7, 9, and 11. The average (ave) of this set is 6, and the standard deviation (sd) is 3.741… . Note that the interval defined by "ave ± sd" includes most but not all of the numbers in this particular set.

• In Column B enter the following numbers: 1, 2, 3, 4, 5, 6. Take note of the average and the standard deviation at the bottom of this column. The standard form for communicating experimental results in this course is as follows: Round the "sd" value to ONE digit (unless the lead digit is a 1, in which case you round the "sd" value to TWO digits), and then round the "ave" value to the same decimal place as the right-most significant digit of the "sd." Then write the results as "ave ± sd." For the given example in Column A, the "ave ± sd" = 6 ± 4. For Column B the "ave ± sd" = 3.5 ± 1.9.

• Now express "ave ± sd" for two more (different) sets, six numbers each, of your own choosing in Columns C and D. Be sure to type the corresponding properly rounded "ave ± sd" into the empty blue cells.

This concludes Part I of this experiment. Now please proceed with Part II.

Part II, Relative Uncertainties

• In Column E of the worksheet is an example set of ten values of four-digit numbers that span a range of no more than ten (5555, 5556, 5557, 5558, 5559, 5560, 5561, 5562, 5563, and 5564). For the example set the "ave ± sd" = 5560 ± 3. Note that there are now additional rows showing the "sd/ave" (the relative uncertainty) in both fractional and percent form. The percent uncertainty is less than a tenth of one percent. If these were your data from an experiment, you would be either an excellent experimentalist or very lucky!

• Put into Column F a set of ten numbers with more variation, perhaps a range of one hundred, such that your standard deviation is a larger percentage of your average. Change the input values until your percent uncertainty lies between one-tenth and one percent. Express the "experimental data" using the standard form "ave ± sd" that was explained in Part I, and place your answer in the blue box.

• Likewise, into Columns G and H, put in sets of ten numbers such that your percent uncertainities lie between one and ten percent, and ten and one hundred percent, respectively, expressing the experimental results in standard form.

• Let's summarize! The whole point of this exercise is that in your lab work throughout this term you will often have to write down the results of some quantity that is based on many individual measurements that the computer characterizes by “ave” and “sd” values. Then you will need to round off these values according to the rules given in Part I in order to communicate properly the results of your experiment.

• In the mechanics laboratory, a ratio of better than 1% is probably blind luck, but if you are careful, you should usually be able to do better than 5%. Anytime that ratio equals or exceeds 10%, you should repeat the measurement in more careful fashion because the equipment you are working is much more accurate than 10%.

• Make sure to change the order of your name and your partner's name at the top of the worksheet for your respective copies. Email them to yourselves such that you have a record of your work in case of any problems with submission for grading. To submit them, each student must log on to the section's myWPI site, select Lab Submissions in the left-hand menu, click on the appropriate link, and attach the local file (your worksheet). Internet Explorer is the most reliable means of submission.

Congratulations! You have now finished your first physics "experiment."

Worksheet

2	**Expressing Uncertainties of Experimental Data**							
3								
4	Please enter your name and section number in this rose box:							
5	Please enter your *partner's* name and section number in this rose box:							
6	Place your numerical values in the empty **tan** cells and your answers in the empty **blue** cells.							
7								
8	**Numerical Values**	**Numerical Values**	**Numerical Values**	**Numerical Values**	**Numerical Values**	**Numerical Values**	**Numerical Values**	**Numerical Values**
9	1				5555			
10	3				5556			
11	5				5557			
12	7				5558			
13	9				5559			
14	11				5560			
15	**Number**	**Number**	**Number**	**Number**	5561			
16	6	0	0	0	5562			
17	**Average**	**Average**	**Average**	**Average**	5563			
18	6.00000000	#DIV/0!	#DIV/0!	#DIV/0!	5564			
19	**Standard Deviation**	**Standard Deviation**	**Standard Deviation**	**Standard Deviation**	**Number**	**Number**	**Number**	**Number**
20	3.74165739	#DIV/0!	#DIV/0!	#DIV/0!	10	0	0	0
21	**Ave ± SD**	**Ave ± SD**	**Ave ± SD**	**Ave ± SD**	**Average**	**Average**	**Average**	**Average**
22	6 ± 4				5559.50000000	#DIV/0!	#DIV/0!	#DIV/0!
23					**Standard Deviation**	**Standard Deviation**	**Standard Deviation**	**Standard Deviation**
24					3.02765035	#DIV/0!	#DIV/0!	#DIV/0!
25				**Relative uncertainty:**	**SD/Ave**	**SD/Ave**	**SD/Ave**	**SD/Ave**
26				**Fractional uncertainty:**	0.0005	#DIV/0!	#DIV/0!	#DIV/0!
27				**Percent uncertainty:**	0.05%	#DIV/0!	#DIV/0!	#DIV/0!
28					**Ave ± SD**	**Ave ± SD**	**Ave ± SD**	**Ave ± SD**
29					5560 ± 3			
30								

Our Analysis of this Laboratory

The “Expressing Uncertainties of Experimental Data” lab is the first lab that is held in PH-1110. This lab is relatively simple, and serves mostly to familiarize students with both data recording and lab submission.

In this lab, students are taught how to properly express results. Students are not given any experiment to conduct. Rather, they are asked to place a series of values into a spreadsheet and present the average and standard deviation in a “standard form”. While this lab makes an effort to prepare students for future labs, the worksheet is especially unhelpful because it does many calculations for the students. Instead, students should practice calculating mean, standard deviation, and uncertainty by themselves.

Additionally, it should be emphasized that to get meaningful and accurate data, it is often advised to conduct multiple trials. While this may be clear for the majority of students, some may not understand the purpose of repeating the process in columns F-H of the worksheet multiple times.

1. Understanding Graphs of Motion

Overview

The purposes of this experiment are to learn how to set up the equipment and use the Logger Pro data acquisition system, to become familiar with x(t) and $v_x(t)$ graphs, and to improve your understanding of the variables of one-dimensional kinematics: x, v_x, and a_x.

There will usually be one or more Logger Pro templates which when opened will provide you with a Logger Pro graph appropriate to the measurement task at hand. Week-by-week you will be learning more about the Logger Pro features that facilitate your measurement and analysis tasks.

In Parts I and II, you will attempt to move the cart such that its motion matches the template that we provide for you. In Part III, you will demonstrate your understanding of the kinematical variables by moving the cart without templates.

Please proceed by clicking on the link to Part I below.
Procedure

Part I, Experimental Set-up

• Place the cart on the track, putting its wheels in the slots. If the cart moves, level the track by adjusting the height of its legs; the feet should be positioned at 60 and 160 cm so that the track does not deform under its own weight. The computer should be connected to an interface box, which in turn should be connected to a motion sensor. Place the motion sensor on the left end of the track. The face of the motion sensor's detector should be vertical.

• Open Template 0. The position of the cart will be plotted on the y-axis, time on the x-axis. The positive direction is away from the motion sensor. If the motion sensor is on the left end of the track, the positive direction is to your right.

• When ready to move the cart to follow the motion shown on the template, start the motion detector by clicking the green Collect Button up on the Logger Pro tool bar (or, alternatively, just press the space bar). Repeat as necessary until each partner can roughly match the template pattern.

• To repeat a run with the same template once the collection has been stopped, just click the green Collect Button (or press the space bar) again – that action erases the previous run and begins another. In fact, you can end a failed run anytime you want by clicking the Collect Button, which is red when the system is collecting.

• Open the worksheet by clicking on the link below. Save it in your server space under a different name. Copy and paste a good experimental match to Template 0, following the directions in Question 1 of the worksheet.

Now you know how to set up your equipment and collect data using Logger Pro. It is time for you to move on to Part II.

Part II, Graphs of x(t) and v_x(t)

• Now we want to help you improve your understanding of x(t) and v_x(t) graphs by giving you more difficult templates to match. There are three more templates to try and match. Each partner should repeat the exercise until a rough match is made. Add an example of a decent match to each template to your worksheet, following the instructions stated in Question 1.

• When done with Template 0, close Logger Pro and open Template 1, repeating the process followed with in Part I. Then try Template 2. These two templates plot position as a function of time, x(t).

• Now try Template 3, which plots velocity as a function of time, v_x(t).

• Did you notice how much harder it is to match a v_x(t) template than an x(t) template? We suspect that it has to do with the fact that we all are accustomed to functioning in a world of displacements, but velocity is (you might say) in a different space – one derivative away from where we live.

Now please proceed to Part III.

Part III, Testing your Understanding of x, v_x, and a_x

• Open the Logger Pro file for Part III, and then try to move the cart in such a manner as to match one of the following four prescriptions for at least a two-second time duration, repeating as necessary in order to accomplish the prescription. You can autoscale them with the “A” button in the top ribbon of the Logger Pro window. If you have time, each student partner should do all four of the following prescriptions. If you have fewer than fifteen minutes left, you should each take a pair of prescriptions.

1. x increasing, v_x reasonably constant
2. X decreasing, a_x positive
3. V_x positive, a_x positive
4. V_x negative, a_x negative

• When you have good data for each of the four prescriptions, copy and paste an example into the box below Question 2 of your worksheet, following the instructions for Question 2.

- In this part, only x(t) and $v_x(t)$ are plotted ($a_x(t)$ is not). The reason for this is that $v_x(t)$ and $a_x(t)$ values are GENERATED from the x(t) data (which are actually MEASURED – by the motion detector), $v_x(t)$ through one process called numerical differentiation, and $a_x(t)$ through two such processes, with the result that a lot of noise shows up in the $a_x(t)$ data. In subsequent experiments you will be shown a sophisticated, computer-appropriate way to extract excellent average acceleration values from the Logger Pro data at hand.

- Yet you only need the x(t) and $v_x(t)$ graphs in order to figure out how to match these various prescriptions, even if acceleration is prescribed! How indeed? In fact, all you really need is the x(t) graph OR the $v_x(t)$ graph! If you don't understand this point, be sure to ask your lab instructor about it if you and your partner cannot figure out the answer by yourselves.

Congratulations! You have almost finished your first introductory physics experiment with equipment. Each partner now only needs to respond individually to Questions 3 and 4 of the worksheet and submit it through myWPI. Make sure to change the order of your name and your partner's name at the top of the worksheet for your respective copies. Email them to yourselves such that you have a record of your work in case of any problems with submission for grading. To submit them, each student must log on to the section's myWPI site, select Lab Submissions in the left-hand menu, click on the appropriate link, and attach the local file (your worksheet). Internet Explorer is the most reliable means of submission.

Worksheet

Name and section number:
Partner's name and section number:

1. To demonstrate your ability to acquire data and follow the motion templates of Parts I and II, please copy and paste an example graph from each of the four templates in the box below. Template 0 should be just above a), Template 1 just above b), etc. Format the graphs such that they are approximately square and about the same size and such that the four graphs take up the rest of this page. Question 2 goes onto the next page.

a) Template 0

b) Template 1

c) Template 2

d) Template 3

2. To demonstrate your understanding of the kinematical variables x, v_x, and a_x, please copy and paste an example graph for each of the prescriptions of Part III. As above, Prescription 1 should be just above a), Prescription 2 just above b), etc. Format the graphs such that they are approximately square and about the same size and such that the four graphs take up most of the rest of the page.

a) x increasing, v_x reasonably constant

b) x decreasing, a_x positive

c) v_x positive, a_x positive

d) v_x negative, a_x negative

Each partner should do Questions 3 and 4 individually; save two copies of this file under different names. Remember to change the order of your name and your partner's name at the beginning of the file. Save the file again after typing in your answer and before you submit it for grading through myWPI. Email it to yourself so that you have a record of your work.

3. In a few sentences in the box below, use physics terms to describe your motion from the lab to

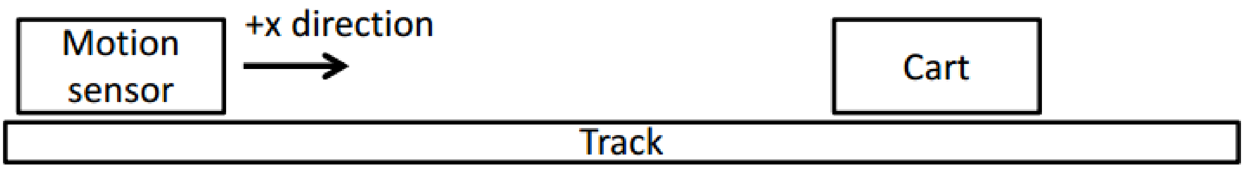
wherever you are going next.

4. What are the names, email addresses, telephone numbers, and office locations of your conference and lab instructors?

Our Analysis of this Laboratory

The Understanding Graphs of Motion Lab focuses on:

- Familiarizing students with the basics of Logger Pro
- Teaching students to capture clean, readable data using lab equipment
- Teaching students to translate motion into readable graphs
- Teaching students to interpret graphs and make conclusions based on data



In this lab, students are given a motion sensor, a cart, and a track. This lab is very introductory, and serves mostly to familiarize students with collecting data and using Logger Pro. Students are given a variety of Logger Pro graphs and are told to trace the shape of the graph by turning on the motion sensor and dragging the cart along the track.

There were a few areas that students seemed to have trouble with. Firstly, the motion sensors have a dead zone of about 6 inches. Any motion inside that range will not be captured correctly. While the TAs were very clear with warning students about the sensor dead zone, some students needed to be reminded again. The instructions make no mention of this shortcoming of the sensor and should be adjusted to explain this limitation.

Additionally, some students encountered dramatic spikes in the sensor's output. We found that most of the time, the spikes were a result of the way that students were holding the cart as they moved it along the track.

In one case, a pair of students needed to unplug and reboot the sensor in order for it to output accurate measurements. While this isn't a frequent issue, it might be useful for students to understand that equipment does malfunction on occasion. A small troubleshooting guide for diagnosing issues with the lab equipment would speed up the lab process.

Because this is the first lab to utilize the Logger Pro software, it would help immensely to provide students with a manual for the software. This would not only allow the TAs to spend more time answering questions about physics and less about the software, but would also likely allow students to complete this lab (and future labs using Logger Pro) in a more timely manner.

While this lab is not very intellectually challenging, it does a decent job introducing students to the structure of the physics labs.

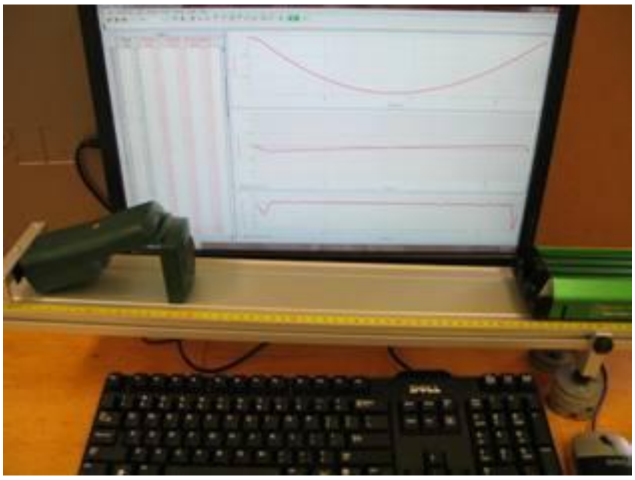
2. One-Dimensional Kinematics

Procedure

Overview

In this experiment, you will study the kinematics (position or displacement, velocity, and acceleration) of a cart under the constant acceleration caused by a slightly-sloped track. You will ensure that the experiment is set up properly and that you understand the graphs of the cart's motion. Then, you will learn more sophisticated functions of the Logger Pro software as you verify if the relationships among the kinematical variables that you have learned in lecture are true in the lab. Along the way, you will measure displacement and velocity in two ways and acceleration in three ways.

Your equipment and data will be similar to those in the picture below.



Today's equipment and example data

Starting with this experiment, for the rest of the term there will be one or more questions at the beginning of the worksheet that you should do *before* going to lab. By thinking about the material before you start the experiment, you will work much more efficiently during the limited time available. If you are not able to answer the questions ahead of time, you should do the experimental work as soon you arrive in the lab so that you have enough time to acquire the data.

This experiment's do-ahead question, Question 1, is very easy: type the kinematical equations for velocity and position in the x-direction for constant acceleration a_x.

Part I, Preparations

- As for the previous experiment, place the cart on the track, putting its wheels in the slots. Check that the track's feet are positioned at 60 cm and 160 cm and adjust them if necessary. The computer should be connected to an interface box, which in turn should be connected to a motion sensor. Place the motion sensor on the left end of the track. The face of the sensor should be vertical. Put masses or other objects beneath the left-hand feet of the track such that the left-hand end is elevated by a few centimeters.

• Practice giving the cart a push from the right-hand end of the track such that it moves at least halfway up the track, but reaches no closer than 20 cm from the sensor. Please catch the cart before it crashes into the stopper at the end of the track.

• Open today's Logger Pro file, and start the motion detector by clicking the green Collect Button up on the Logger Pro tool bar (or, alternatively, just press the space bar). You can Autoscale the graphs with the "A" button in the top ribbon of the Logger Pro window. It is likely that parts of your graphs are neither interesting nor relevant. For example, the cart might have been sitting at rest for several seconds, or there might be glitches in your data. With the cursor, highlight the bad parts of one of the graphs. You'll see the corresponding parts of the other graphs highlighted as well. The Data Browser is on the left-hand side of the Logger Pro window. Scroll down the browser until you see the highlighted data that corresponds to what you have highlighted on the graphs. Under the Edit menu, select Strike Through Data Cells. You'll see the data disappear, both in the browser and on the graphs.

• Your x(t) and $v_x(t)$ data should be free of noise, although your $a_x(t)$ data might be noisy. Now is the time to ask your lab instructor for help if your data are poor or if you are not confident of how they should appear.

• Reflect for a moment. Do you understand why the curves look the way they do? Why is the x(t) graph a parabola, and why is the $v_x(t)$ graph more-or-less linear? Can you guess why the $v_x(t)$ graph has two slightly different slopes? What would happen to the curves if the track were tilted the other way?

With your equipment properly set up and your understanding of the graphs sound, it is time to learn about more sophisticated aspects of Logger Pro as well as the relationships among the kinematical variables. Please click on the link to Part II.

Part II, Displacement and Velocity

In this part, you'll measure displacement and velocity – each in two ways – while also learning about Logger Pro's analysis functions. If you have not already, open the worksheet for today (link below).

• **Displacement Measurement #1:** Take the cursor and highlight an area of the x(t) plot when the cart was in motion by clicking on the curve at an integer time, e.g. 2 s, and dragging the cursor to another integer time, e.g. 6 s. Place the cross of the cursor directly on top of your curve at the beginning and end of the time interval; the opposing corners of the darker gray box that you make with the cross of the cursor must correspond to the start and stop data points. In the lower left-hand corner of the plot, the *magnitude* of the displacement, $|\Delta x|$, is displayed. Copy and paste this plot into the appropriate place in Question 2 of the worksheet, making sure that the magnitude of the displacement is readable.

• **Displacement Measurement #2:** Highlight the same area of the $v_x(t)$ plot as you did for the x(t) plot. Use the Integrate function to find the area under the velocity curve. It is the unnamed button located between the "STAT" and "R=" buttons on the upper toolbar. The magnitude of the area should be close to the value you got above for the magnitude of the displacement. Copy and paste this plot into the appropriate place in Question 2 of the worksheet, making sure that the value of the area and the data are readable.

• **Velocity Measurement #1:** Make the integration disappear by clicking on the cross in the upper right-hand corner of the integral data box. Select the Examine toolbar button labeled "X=". The information goes away if you click on the same function button. Move the vertical bar along the velocity curve to an integral time, e.g. 4 s. Copy and paste this plot into the appropriate place in Question 3 of the worksheet, making sure that the value of the velocity and the data are readable.

• **Velocity Measurement #2:** Undo the Examine function by clicking on the button again. Select the x(t) graph, and click on the Tangent function labeled "M=", just to the right of the Examine function. Move the tangent cursor to the same time as you did for the previous step. The tangent (slope) should be close in value to the velocity at your chosen time. Copy and paste this plot into the appropriate place in Question 3 of the worksheet, making sure that the value of the slope and the data are readable.

Please move on to Part III.

Part III, Acceleration and Relationships

In this part, you'll measure acceleration in three ways while also learning more analysis functions.

• **Acceleration Measurement #1:** Take the cursor and highlight a time interval of the $a_x(t)$ plot when the cart was in motion by clicking on the curve at an integral time, e.g. 2 s, and dragging the cursor to another integral time, e.g. 6 s. Use the Statistics function, to the right of the Tangent function in the upper toolbar, to find the mean value of the acceleration in your chosen time interval. Copy and paste this plot into the appropriate space in your worksheet, making sure that the mean value of the acceleration and the data are readable.

• **Acceleration Measurement #2:** Highlight the same time interval of the $v_x(t)$ plot as you did for the $a_x(t)$ plot. Use the Linear Fit function of the button labeled "R=" on the upper toolbar to find the slope of the velocity curve. The slope should be close to the value you got above for the mean value of the acceleration. Copy and paste this plot into the appropriate space in your worksheet, making sure that the value of the slope and the data are readable.

• **Acceleration Measurement #3:** Return to the x(t) graph. Select the same time interval and apply the Curve Fit function of the button labeled "f(X)=", to the right of the Linear Fit button on the upper toolbar. The Curve Fit pop-up window will appear. Select Quadratic General Equation, then Try Fit, then OK. The variable A of $x=At^2+Bt+C$ should be approximately equal to one-half the mean value of the acceleration from the $a_x(t)$ plot. Copy and paste this plot into the appropriate place in Question 4 of the worksheet, making sure that the value of A and the data are readable.

• Summarize your numerical results in Question 5 of the worksheet.

• Each partner should do Question 6 individually, in which you state in your own words the graphical and mathematical relationships among the kinematical variables. Make sure to change the order of your name and your partner's name at the top of the worksheet for your respective copies. Email them to yourselves such that you have a record of your work in case of any problems with submission for grading. To submit them, each student must log on to the section's myWPI site, select Lab Submissions in the left-hand menu, click on the appropriate link, and attach the local file (your worksheet). Internet Explorer is the most reliable means of submission.

We hope you now appreciate all the kinds of analysis that Logger Pro can do and have a solid understanding of one-dimensional kinematics. If you do not, please ask for help!

Worksheet

Name and section number:
Partner's name and section number:

1. Type the kinematical equations for velocity and position in the x-direction for constant acceleration a_x.

2. Copy and paste the measurements of displacement into this box: a) should be the x(t) plot and b) the v_x(t) plot. Ensure that the displacement data and data boxes are readable.
a)

b)

3. Copy and paste the measurements of velocity into this box: a) should be the v_x(t) plot and b) the x(t) plot. Ensure that the velocity data and data boxes are readable.
a)

b)

4. Copy and paste the measurements of acceleration into this box: a) should be the a_x(t) plot, b) the v_x(t) plot, and c) the x(t) plot. Ensure that the acceleration data and data boxes are readable.
a)

b)

c)

5. Summarize your results.

Δx_a =	Δx_b =	
v_a =	v_b =	
a_a =	a_b =	a_c =

Each partner should do Question 6 individually; save two copies of this file under different names. Remember to change the order of your name and your partner's name at the beginning of the file. Save the file again after typing in your answer and before you submit it for grading through myWPI. Email it to yourself so that you have a record of your work.

6. In a few sentences in the box below, compare the sets of measurements for each of the three variables. Do they agree? Describe the graphical and mathematical relationships among them.

Our Analysis of this Laboratory

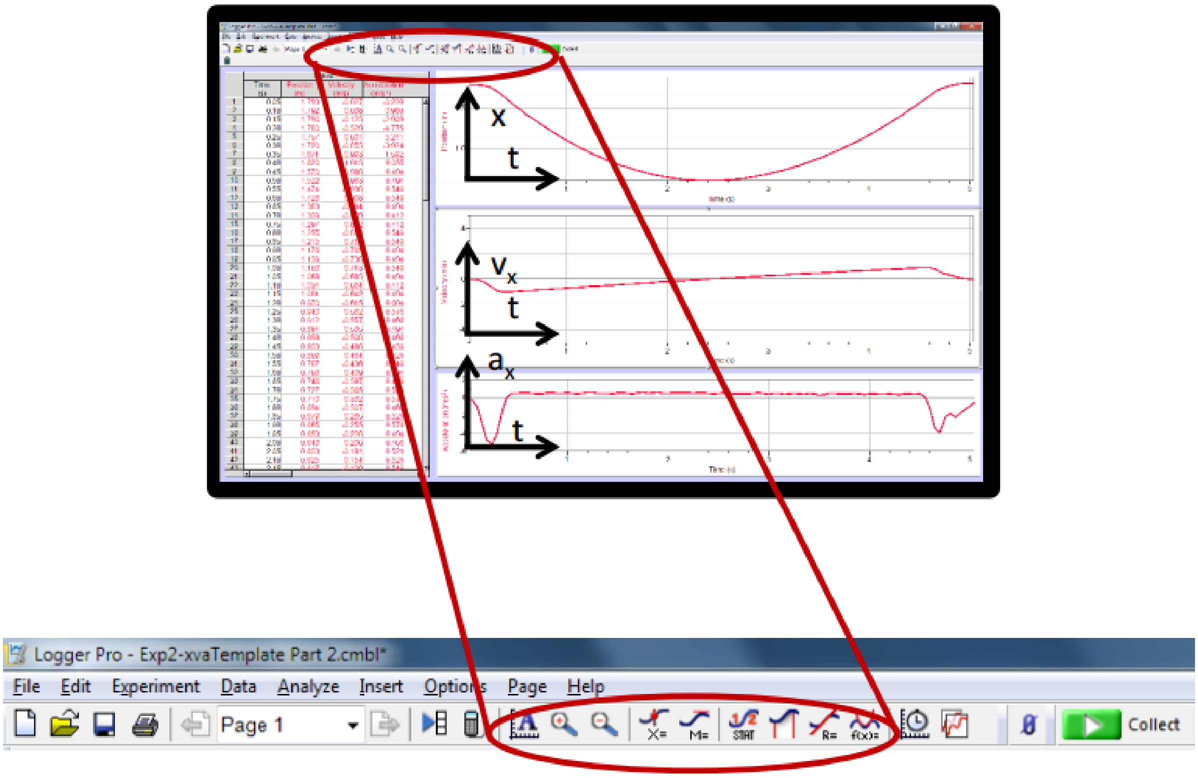
PH-1110's One-Dimensional Kinematics Lab serves to:

- Increase student familiarity with interpreting graphs of one-dimensional motion
- Teach students to measure displacement, velocity, and acceleration in different ways

- Increase familiarity with the Logger Pro software

In this experiment, students are given a cart, a slightly sloped track, and a motion sensor. By giving the cart a gentle push up the track and collecting data with the sensor, students are expected to discover the relationship between position, velocity graphs, and acceleration. Additionally, students will discover that taking the first derivative of a position graph will yield velocity, and taking the first derivative of velocity will yield acceleration.

In the overview page included with this lab is a photograph depicting fully labeled sample data. In order to ensure that students are able to comprehend their own results, no photographs of data should be included in the lab instructions.



Immediately, we noticed that students had a difficult time using the Logger Pro software. We believe that a quick, ten minute Logger Pro presentation would be extremely helpful in reducing the volume of software related issues throughout the course. This presentation could be given to students during conference, or at the start of the lab. The students were not the only ones that felt unaccustomed to using the software. Some of the TAs admitted that even though they were familiar with the lab material, they did not have enough exposure with Logger Pro to help students as much as they would have liked. We noticed that on multiple occasions, one TA needed to explain certain aspects of the software to the other.

One of the most apparent difficulties with the software throughout this experiment was with the way that Logger Pro displays data that has been highlighted with the mouse. When highlighting regions of data in Logger Pro, there are two boxes that students see:

- A dark gray box – showing the highlighted data
- A light gray box – showing the highlighted time interval.

One group had trouble getting the integral of their position graph because they misinterpreted the selection box. They thought that the light gray box was showing the entire selected region. As a result, they recorded incorrect data into their worksheet. Thankfully, they noticed their mistake and the TA was able to guide them in the right direction. However, looking around – we noticed that there were at least two other groups that made this mistake and did not seem to realize it.

This lab was not very challenging for students, and most groups were able to finish in about thirty minutes. Collecting data for the displacement and velocity was not very difficult for most students – but reading and interpreting the on-screen results seemed to be more challenging. Because students were able to finish with so much time left over, perhaps some time could be taken at the beginning of the lab period to better introduce the software to students.

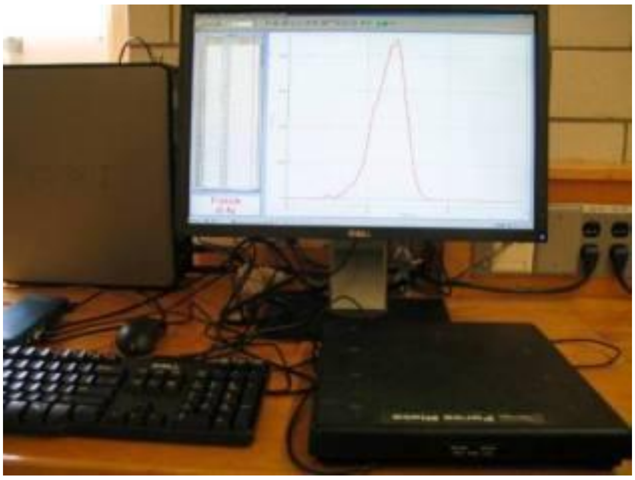
3. Free-Body Diagrams

Procedure

Overview

In lecture, we have emphasized the usefulness of free-body diagrams, in which the forces acting on a particular object by other objects are sketched by means of vectors. In today's experiment you will measure forces by means of a force plate, and then you will be asked to sketch the corresponding free-body diagrams in your worksheet.

There are three parts to this experiment. Part I asks some preparatory questions, Part II concerns equilibrium, and Part II acceleration. You should do Part I in advance of coming to lab. If not, do Parts II and III, then return to Part I to complete the worksheet.



Today's equipment and example data

Part I, Preparation

• You should answer Questions 1 and 2 on the worksheet before you go to lab. For Question 1 you are to sketch free-body diagrams of you, a table, and a force plate while you are in equilibrium standing on the force plate (which is on the floor), pushing down on a table. For Question 2 you are to sketch free-body diagrams for you and a force plate while you are jumping (accelerating) *up and off* a force plate.

• On the worksheet, vertically enlarging the drawing canvas will make it easier to insert arrows and text boxes; you may copy, paste, and modify the given examples in Question 1. You might need to go to Drawing Tools → Align → Grid Settings to undo object snapping. Change the colors of the vectors from black to gray for any action-reaction pairs within each of the three sets of sketches. Use the defined abbreviations in the questions in order to be kind to the graders.

Start Part II as soon as you arrive in lab.

Part II, Equilibrium

• Before you do anything else, please check that the switch on one of the sides of the force plate is properly set. It should be at the setting marked

-800/+3500 N.

The switch is just below the word "Range."

• Open today's Logger Pro file. Place the force plate on the floor and zero the force value. Start collecting data. One student should slowly step onto the force plate, remain motionless for a few seconds, then step off. Both students may try.

• Then one student should step onto the plate, and the other student should zero the force. Acquire data while the student slowly picks up some masses or a book, then sets the object(s) down. You will probably have to use the Autoscale button to see the data well. Did the force on the plate go up or down while holding the object?

• Alternate students. For this step and future ones, zero the force again if necessary. Collect a curve while you start pushing down on the table, holding the force for a few seconds, then slowly releasing it. Copy and paste this plot into the box below Question 3 of the worksheet. Ask yourselves if the data are consistent with the free-body diagrams you made in response to Question 1.

Feel free to try other variations on equilibrium (no acceleration) measurements before moving on to Part III.

Free-Body Diagrams

Part III, Acceleration

• The switch on the force plate should still be at the setting marked

-800/+3500 N.

• Zero the force plate without any mass on it. Start to acquire data, step gently onto it, remain motionless for a moment, and then jump **UP and OFF** the plate, landing on the floor. You will break the plate if you land on it. Put a copy of these data into the box below Question 3 of the worksheet and answer Question 3c.

• If you are interested, you can calculate the ratio of your peak force minus your weight over your weight. A ratio greater than 1 indicates good physical condition. (Personal trainers and fitness clubs sometimes use force plates for tests of this kind.)

• While collecting data and standing on the force plate, pick up a mass or a book of at least 500 g and drop it from one hand to the other. Please make sure to catch the object, or at least ensure that the object does not drop onto the force plate. Make sure you understand the shape of the curve before moving on to the next step. Paste these data as your response to Question 5a.

• Then acquire data while standing on the plate and throwing and a mass or book up in the air and catching it. Paste these data as your response to Question 5b.

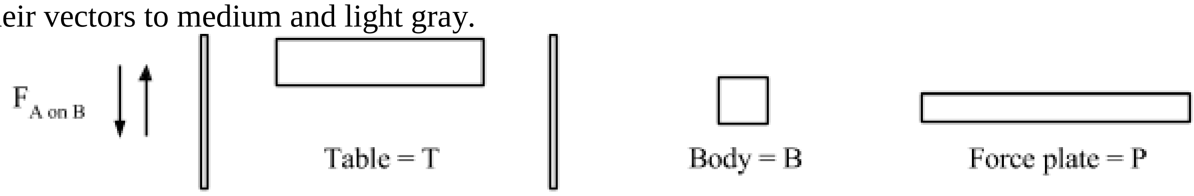
• Answer Question 6 individually. We shall no longer repeat the admonitions about how to save and submit your files.

You are welcome to repeat any of these activities. Sketching proper free-body diagrams is a crucial skill for success in mechanics. We hope that this experiment and worksheet will help you master this skill.

Worksheet

Name and section number:
Partner's name and section number:

1. Sketch the forces acting on the table, your body, and the force plate while you are standing in equilibrium on the force plate (which is on the floor), pushing down on the table. Clearly label each force using the form $F_{A\ on\ B}$, where "A on B" means Object A acting on Object B. In addition to Table = T, Body = B, and Force plate = P, use Earth = E and Floor = F. Two pairs of forces in these sketches make up two action-reaction pairs. Denote these pairs by changing the colors of their vectors to medium and light gray.

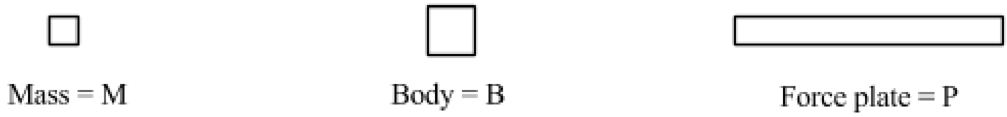


2. Sketch the forces acting on you and the force plate while you are accelerating upwards just prior to jumping off the plate. Label them and change their colors as described in Question 1.

3. Put graphs into the box below showing a) the force-plate data as a student pushes down upon the table, and b) the data as the same student jumps *up and off* the force plate. For c), explain why in one case the force is less than the student's weight, and in the other case it is more.
a) b)
c)

4. Sketch the forces acting on the mass, your body, and the force plate while you are catching the

mass after having dropped or thrown it. Label them and change their colors as described in Question 1, also using Mass = M.



5. Put graphs in the box showing the force as you a) drop and catch, b) throw and catch a mass.

a) b)

6. *In your own words,* compare the graphs you inserted for Question 5. Explain their features.

Our Analysis of this Laboratory

The Free-Body Diagram lab serves to:

1. give students experience in analyzing the motion of two interconnected objects with linked motion.

2. Explore the relationship between friction, acceleration, and angle

In this lab, students place a cart on top of a ramp with a pulley at the top. The students are told to push the cart down the ramp and calculate the angle of the ramp and the magnitude of the friction of the cart as it moves up/down the track.

One of the largest problems with this lab (and other 1110/1111 labs) is the lack of clear diagrams within the lab instructions. On the “overview” section of the lab procedure is a photograph of the lab setup, but it is very difficult to set up the experiment with just this picture. The TA drawn board diagrams were much more effective, and ideally, these should be included in the lab instructions.

While the TAs were able to answer most student questions, we did notice that one student got their string stuck on the edge of the track (instead of on the pulley). As a result, the student had a difficult time performing the experiment and needed to re-conduct this portion of the lab. In order to prevent this from happening in the future, it would be helpful if the TAs warned students to double check that their setup is correct before collecting any data. These kinds of reminders are especially important in the early labs because the majority of students have not yet developed good lab habits.

Additionally, students should also be careful to make sure that the cart is placed properly on the track. One student was unable to get his cart to enter equilibrium. At the bottom of the track (close to the surface of the table), the cart would slowly rise. The cart was not seated properly and therefore the student was getting unexpected results in his data.

Like the PH-1111's Lab 2, students encountered a variety of problems using Logger Pro. One student was trying to open the Logger Pro template on his personal laptop. Apparently some students do not realize that the Lab computers are the only PCs equipped with the software. Giving students access to Logger Pro at home would not only allow students to increase their familiarization with the software, but also enable to students to work with (and view) their data after the end of the lab period.

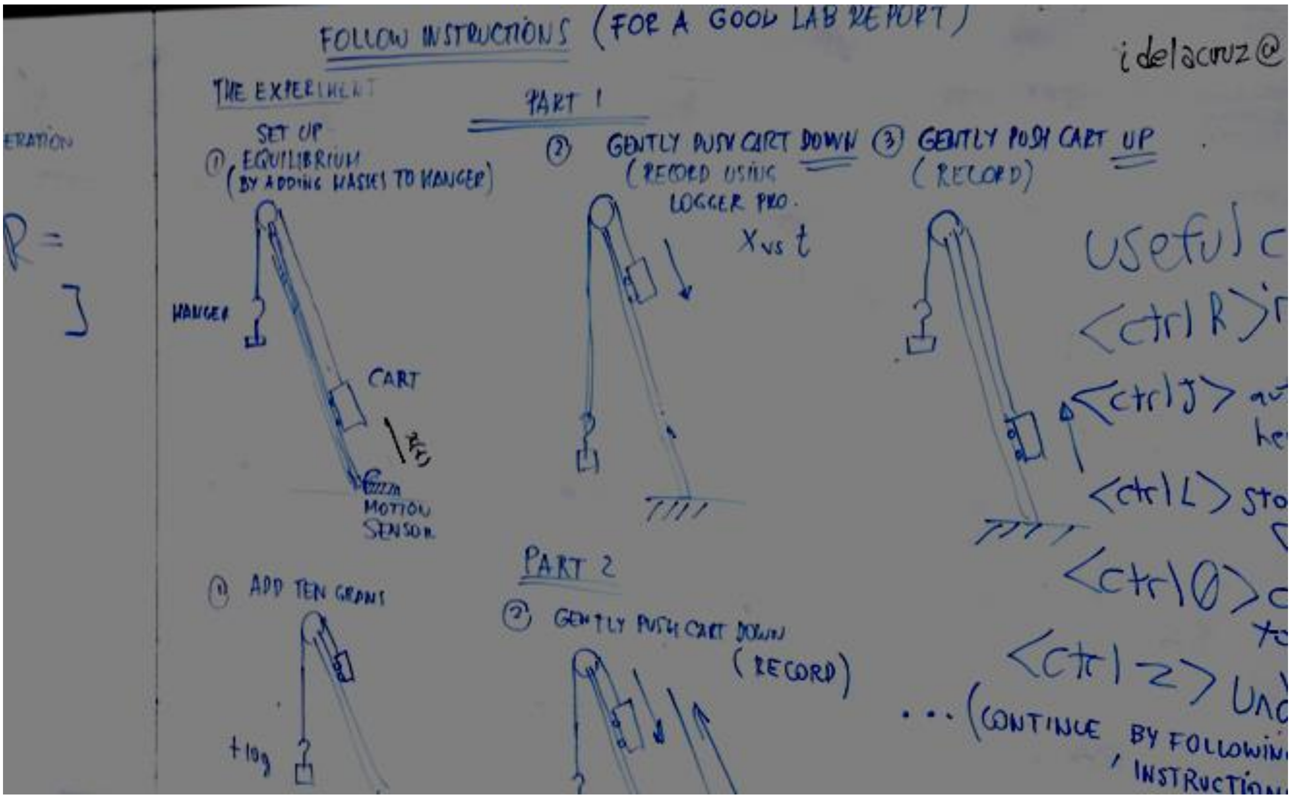
We also noticed that there was a large amount of confusion in finding the least squares fit using Logger Pro. Because lab #1 has students calculate the least squares fit by hand, many students seemed to think that this calculation could be done "at home", whereas in this lab, the instructions are describing logger-pro's linear fit tool.

One question that students asked a few times: *"When I am doing part 2 (pushing the cart down the track and letting it come back up), should I be recording the part when the cart moves down the track, or up the track?"*

Students were not realizing that even though the velocity and position were changing (from positive to negative), the cart accelerates at a constant rate. So the answer is both.

The instructions at the end of part 1 were challenging for some students to understand. It should be made more clear that students are expected to gently tap the cart, let go, and allow the cart to coast.

Finally, the TAs noted that there is a lot of variation in the amount of effort that lab groups put into the lab worksheet. Some students do much less than is expected, while others do much more than expected. The TAs recommended that the worksheet expectations are made more clear to students


FOLLOW INSTRUCTIONS (FOR A GOOD LAB REPORT)
THE EXPERIMENT
PART 1
SET UP
① EQUILIBRIUM
(BY ADDING MASSES TO HANGER)
HANGER
CART
MOTION SENSOR
② GENTLY PUSH CART DOWN
(RECORD USING LOGGER PRO.
x vs t
③ GENTLY PUSH CART UP
(RECORD)
<ctrl R>
<ctrl J>
<ctrl L>
<ctrl 0>
<ctrl z>
PART 2
① ADD TEN GRAMS
+10g
② GENTLY PUSH CART DOWN
(RECORD)
...(CONTINUE BY FOLLOWING INSTRUCTIONS

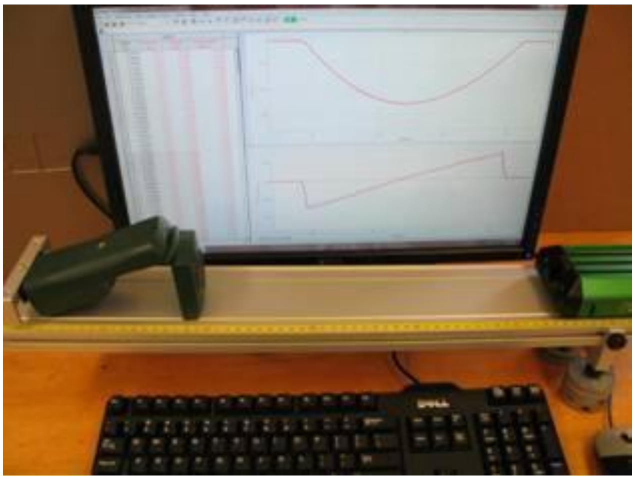
4. The Mass-Dependence of Friction

Procedure

Overview

You have developed many skills in lab so far: expressing uncertainties, setting up and using the equipment and software properly, understanding kinematics, and drawing free-body diagrams. You are ready to make a prediction and test it. You are to predict which variables associated with friction are dependent on mass and then run an experiment to see if you are correct.

There are two parts to this experiment. Part I concerns the theory and Part II, the experiment. This worksheet begins with questions from Part I that you should try before coming to lab. If you come to lab without having done Part I, go immediately to Part II and collect the raw data (#4 and the yellow boxes of #5 on the worksheet). Then return to Part I. The calculations of #5 can be done later, although of course it is preferable to finish while you are still in lab and can direct any questions you might have to your lab instructor.



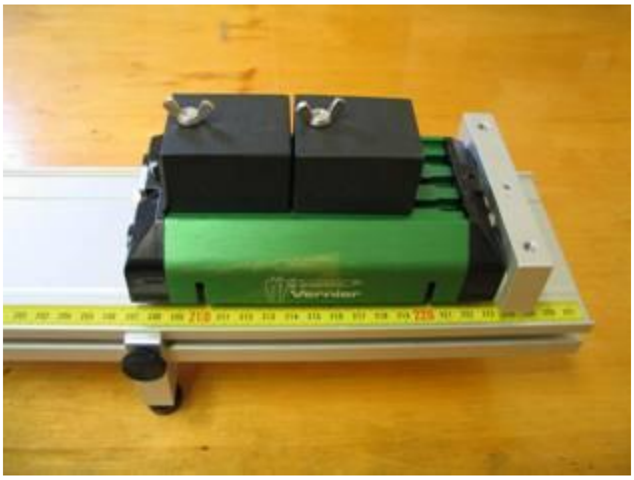
Today's equipment and example data

Part II, Experiment

• Set up the equipment as for the kinematics experiment, where you detected the motion of a cart on a slightly sloped track. Open today's Logger Pro file.

• Determine the angle of the track using a ruler and your knowledge of trigonometry. Enter the value into the table in the worksheet. It is easiest to keep the angle of the track the same; enter the angle into all three rows corresponding to the three trials you are about to do.

• Your cart might or might not have one or two additional masses screwed to it, as in the pictures below. Measure the mass of your cart using a mass balance, as in the right-hand picture. The masses are attached to the cart by means of a bolt and wing-nut. Your lab instructor can show you the easiest way to secure them. Upon removing a mass, please replace the bolt in the hole and tighten the wing-nut so that these small parts do not get lost.



Left: cart and masses on track; right: cart and masses on mass balance.

• Measure the accelerations of the cart as it moves up and down the slope, as you did for the kinematics experiment, in which you found acceleration as the slope of a Linear Fit ("R=" button in the upper toolbar) to the velocity. Display the standard deviation of the slope by right-clicking on the data box and choosing Show Uncertainty. Do this for the cart with no additional mass, one additional mass, and two additional masses.

• You may do the three measurements in any order. The accelerations for up and down the slope should be slightly different. (Do you understand why?)

• Copy and paste your graphs into Question 4 of the worksheet, making sure that you can see the data and read the data boxes, with standard deviations. You might need to decrease the size of the plots, such that the data boxes consume a larger portion of them. Fill in the table with the three mass values and the six accelerations. Type in the relevant units within the square brackets at the top of each column. Calculate N, f, and μ based on your equations. All values in the table should have four significant digits. Find the average of the three measurements for N, f, and μ.

• Logger Pro calculates the "sample standard deviations" of linear and quadratic fits. We have not yet told you how they are calculated. The equation is

$$sd = SQRT \{ [\sum_i (x_i - x_{ave})^2] / (n-1) \},$$

where x_i is an individual measurement, x_{ave} the average of the measurements, and n the number of measurements. Compute the standard deviation for the columns N, f, and μ, and then determine the fractional uncertainties, sd/ave. Of the three variables, two should have large fractional uncertainties, and one should have a small fractional uncertainty, less than 0.100. (Why?)

• In reporting your results for the last question on the worksheet, remember to follow the standard form that you learned in Part I of the uncertainties experiment. Please answer the last question individually, in your own words.

If all has gone well today, you have made some predictions about the dependence of the friction variables N, f, and μ on mass and verified your predictions experimentally.

Worksheet

Name and section number:

Partner's name and section number:

1. Make free-body diagrams of a cart moving up and down the track. Label the forces.

2. Based on the above, write out Newton's Second Law for each direction for both situations.

Up: $\Sigma F_x = ma_u =$ Down: $\Sigma F_x = ma_d =$

$\Sigma F_y = 0 =$ $\Sigma F_y = 0 =$

3. Solve the above equations for N, f, and μ. Answers must be in terms of m, g, a_u, a_d, and θ.

N = f = μ =

4. Insert into the box the $v_x(t)$ graphs for the three measurements, with data and boxes readable.

a)

b)

c)

5. Fill in this table, stating the units within the square brackets, and using four significant figures. If you are pressed for time, collect data now (yellow boxes) and calculate later (green).

Trial	θ []	m []	a_u []	a_d []	N []	f []	μ []
1							
2							
3							
				Average:			
				Std dev:			
				Sd/ave:			

6. *In your own words,* summarize your results for N, f, and μ, using the standard form that you learned in Experiment 0. Explain why the fractional uncertainty, sd/ave, for one variable is so much different than for the other two.

Our Analysis of this Laboratory

The goals of the Mass Dependence of Friction Experiment are:

1. Acquire a better understanding of the relationship between mass and friction.

2. Gather data and acquire values for N, f, and μ.

All PH-1110 labs have an "Overview" page that is attached to the lab instructions. In Lab 4, the overview section does a good job introducing the lab to students, but is very undescriptive in its description of the lab's "central concept":

"It is possible to both predict and verify behavior, as you will do in this experiment."

It is good to see that the overview does not reveal the conclusion of the lab, but it still does a poor job explaining the objective of the experiment.

Immediately, we noticed that Part 2 of the experiment tells students to "set up the equipment as for the kinematics experiment, where you detected the motion of a cart on a slightly sloped track". The underlined portion links to PH-1110's Lab 2. This link should be removed and the set up instructions should be copied into this lab procedure. The current layout is not ideal because if the setup for Lab II needs to be changed in the future, it could potentially conflict with the intended setup for this lab. Additionally, if the URL for Lab II ever changes, then the link in these instructions will break as a result. This same mistake is made later on in the procedure – the instructions tell students to "follow the standard form that you learned in Part I of the uncertainties experiment". (the underlined text links to PH-1110's Lab 1). Additionally, telling students to follow the same format for representing results may give students the idea that there is a single, universally applicable method for reporting results. While a standard form is useful for organization, not all experiments will necessarily require that data is presented in the exact same way. Different circumstances may require a different approach – and this should be made clear to students.

Next, because this is many students' first year at WPI, standard deviation is an unfamiliar concept to many. The TAs commented that many students do not have the necessary statistics background. In addition, some students were not familiar with the equation:

$$sd = SQRT \{ [\sum_i (x_i - x_{ave})^2] / (n-1) \},$$

TAs recommended that standard deviation be briefly covered in conference so that students are more familiar with it when coming to lab.

In addition, the beginning of the lab instructions tell students to draw the free body diagrams in a notebook or on a piece of scratch paper, but the worksheet contains a section for the free body diagrams. The instructions should be cleaned up for consistency. Since the worksheet designates a spot for a free body diagram, the scrap paper option should be deleted.

There were also some problems with the lab equipment. One of the largest issues that we noticed with the equipment is the sensor dead zone. The sensors will not correctly collect data from anything that is less than ~6 inches from the sensor. The time spent getting lab equipment working as it should takes away from the time that students have to complete the lab. Additionally, we noticed that having more than one instance of Logger Pro open on a single computer prevents the sensors from being detected. The TAs noted that in some cases, the problem can only be fixed by completely rebooting the computer. Students need to completely reboot the computers to solve the problem.

Finally, in this experiment, most of the tracks are set to (approximately) 10 degree angles. Reducing this angle will make the force of friction more apparent.

Overall, this lab teaches students some important concepts about the relationship between mass and friction and is definitely one of the more effective labs that is offered in PH-1110. However, the quality of the lab could benefit greatly from the consideration of the above suggestions.

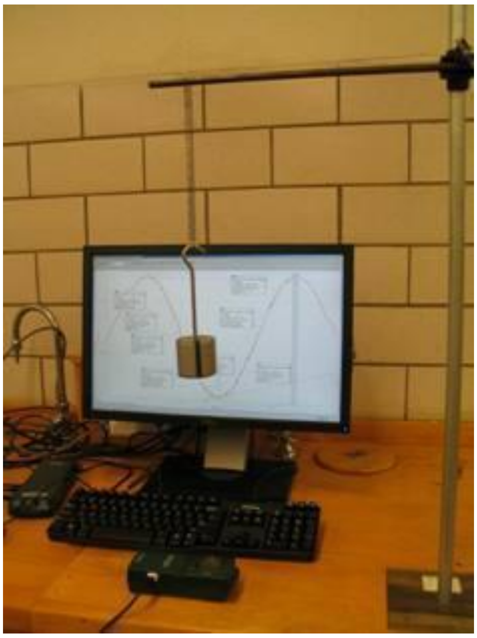
5. Conservation of Energy

Procedure

Overview

You have likely heard that "energy is conserved." This lab explores whether or not that is actually true. You will set a mass on the end of a spring into oscillation and determine its gravitational and spring potential energies, as well as its kinetic energy, at various positions in its oscillation to see if the energies add up to the same total. The sum of the kinetic and potential energies is called the mechanical energy.

There are two parts to this experiment. Part I concerns theory and Part II, the experiment. Ideally, you have tried Part I before arriving in lab so that you will have plenty of time to complete the worksheet. If not, start with Part II. Collect the data for Questions 4-6 on the worksheet, then return to Part I.



Today's equipment and sample data

Part I, Theory

- Make free-body diagrams of a mass oscillating up and down on the end of a spring for three situations: equilibrium, accelerating up, and accelerating down. Label the forces using mg and ky, the magnitude of the spring force. Also indicate if the situation corresponds to the top, middle, or bottom of the oscillation.

- If the zero of the potentials is the unstretched position of the spring, write out the gravitational and spring potentials, as well as the kinetic energy, for the top, middle, and bottom, of the oscillation. Use the variables m (mass), g (magnitude of gravitational acceleration), y_t, y_m, y_b (y-positions), v_m (speed at middle), and k (spring constant), where the subscripts refer to top, middle, and bottom. The positive direction of the coordinate system that we are using is up.

- Write the total mechanical energy (kinetic plus potentials) for each of the three situations: top, middle, and bottom.

When you are satisfied with what you have predicted, open today's worksheet and answer Questions 1-3. Check with your lab instructor to confirm that your free-body diagrams and equations are correct. Then move on to Part II.

Part II, Experiment

• Open today's Logger Pro and spreadsheet files. Place the 500-g mass on top of the hanger. Use the mass balance to determine the mass of the hanger plus the 500-g mass, and enter it into the appropriate yellow cell in the spreadsheet.

• Hang the spring from the equipment stand and stabilize the combined mass hanger and 500-g mass in its equilibrium position. Adjust the height of the bar of the equipment stand such that the bottom of the hanger is about 30 cm above the table.

• Remove the 500-g mass. Center the active element of the motion sensor below the hanger. It may be useful to use a meter-stick or similar object to line up the sensor. Click on the Zero button in the top toolbar, just to the left of the green Collect button. This tells the motion sensor that you want the zero of position to correspond to the bottom of the hanger where the spring is unstretched, as it nearly is when it supports only the hanger.

• Gently replace the 500-g mass on the hanger such that the mass does not drop onto the motion sensor. Slowly return the hanger to its equilibrium position. Then pull it down from equilibrium by just a few centimeters and smoothly release it such that it moves only in the vertical direction. Collect data. You will see a sine wave. If nothing shows up on the graph, you might have to autoscale it. Click on the Curve-Fit button at the top of your screen. In the pop-up window, scroll down the list of functions until you read “A sin(Bt+C) + D” and choose it. Click on “Try Fit,” then “OK.” A solid black line will appear on the screen, along with the fitted values for A, B, C, and D. The value B is the radial frequency, which you should enter into the appropriate yellow cell in the spreadsheet.

• Undo the curve fit. Zoom in on one clean (i.e. no noise) period by highlighting the interesting region, right-clicking the screen, and choosing “Zoom In” on the top toolbar (magnifying glass with “+” sign). Use the Linear-Fit (“R=”) function to find the slope at nine sets of three adjacent points, roughly equally spaced, of one period. Use the Examine (“X=”) function to determine the position and time for each central point of your linear fits. Record the time, position, and velocity for each of your nine central points in the yellow cells of the spreadsheet. Copy and paste the fully annotated Logger-Pro plot that includes the nine different linear-fit data boxes into the answer box for Question 4 of your worksheet. You might need to decrease the size of the plot, such that the data boxes consume a larger portion of it.

• Enter the time of your first datum point of your sequence of data into the yellow time-offset cell of the spreadsheet in order to start the time axis at zero. If your fractional uncertainty (the standard deviation divided by the average, the bottom value of the green cells) is not less than 0.100, you should ask a lab instructor what might be wrong.

• Copy and paste the data within the bold outline of the spreadsheet into the area below Question 5 of your worksheet. Copy and paste the E(t) graph from the spreadsheet into the answer box for Question 6. Read the information in the green cells of the spreadsheet in order to individually report your result for E(t) in <u>standard form</u> for Question 7. Finally, individually answer the other parts of Question 7.

If all has gone well today, you have confirmed that mechanical energy is conserved for a mass on a spring.

Worksheet

Name and section number:
Partner's name and section number:

1. Make free-body diagrams of a mass oscillating up and down on the end of a spring for three situations. Label the forces using mg and ky, the spring force. Also indicate if the situation could correspond to the top, middle, or bottom of the oscillation.

2. If the zero for the potentials is the position of the mass when the spring is unstretched, write the gravitational and spring potentials and kinetic energies for the top, middle, and bottom positions when the mass is oscillating around its equilibrium position using m, g, y_t, y_m, y_b, v_m, and k. The subscripts refer to the top, middle, and bottom of the oscillation.

Top: U_g =	Middle: U_g =	Bottom: U_g =
U_s =	U_s =	U_s =
K =	K =	K =

3. Use the information above to write the total mechanical energy for each situation.

E_{top} = E_{middle} = E_{bottom} =

4. Insert into this box the annotated y(t) graph from Logger Pro, with data and boxes legible.

5. Insert into this space the outlined data from the spreadsheet.

6. Insert into this box the E(t) graph from the spreadsheet.

7. *Individually* report your result for E(t) in standard form. State whether or not mechanical energy is conserved and how the E(t) graph supports your conclusion. Describe how energy is converted from one form to another.

Our Analysis of this Laboratory

This lab focused on observing the mechanical energy of a mass-spring system over time. By completing the experiment, students are expected to observe that total mechanical energy is conserved in the system. While this lab is useful in teaching students about the conservation of energy, there are some opportunities for improvement within this experiment.

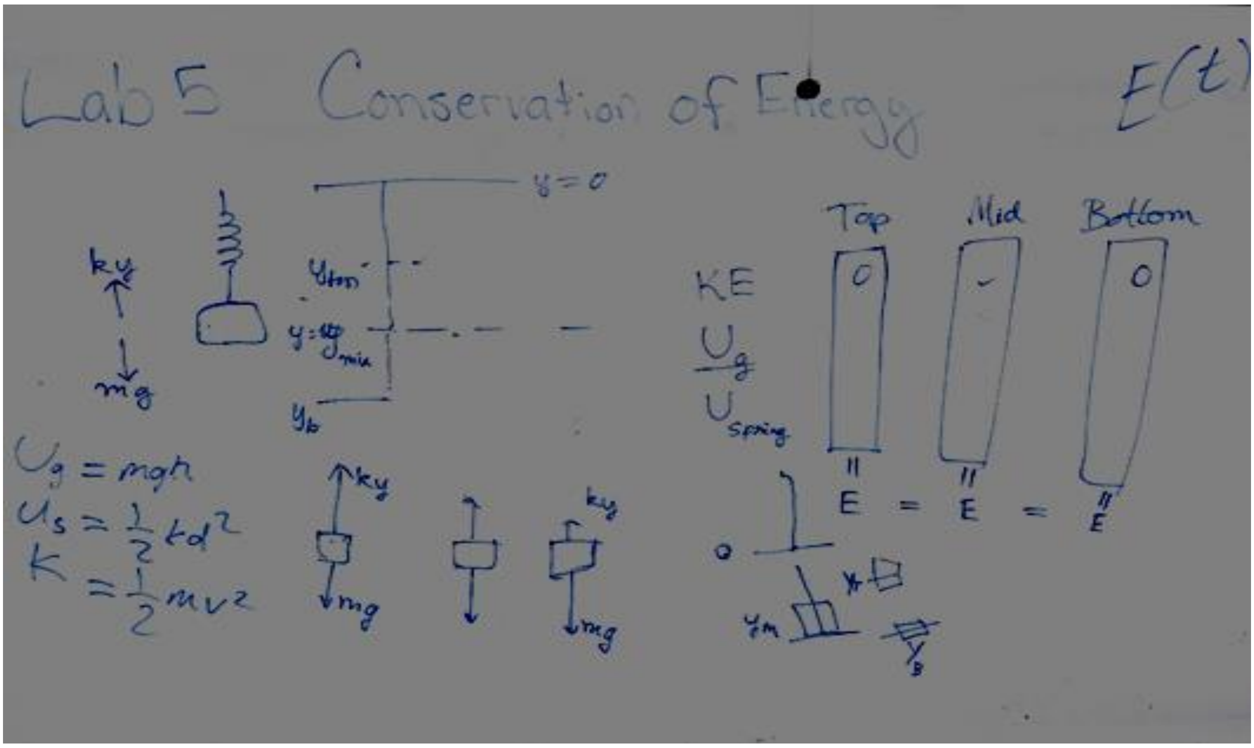
First, we noticed that many groups were pulling their masses too far down. This makes data collection more difficult because it can cause the spring system to oscillate faster than the sensor can accurately record. By making smaller oscillations (as intended), the resulting graph has points that are much closer together and produce much better results. The lab instructions tell students to pull the spring down “a few centimeters”. Some students took this to mean 2-3 cm, while others pulled their masses much further (5-6cm).

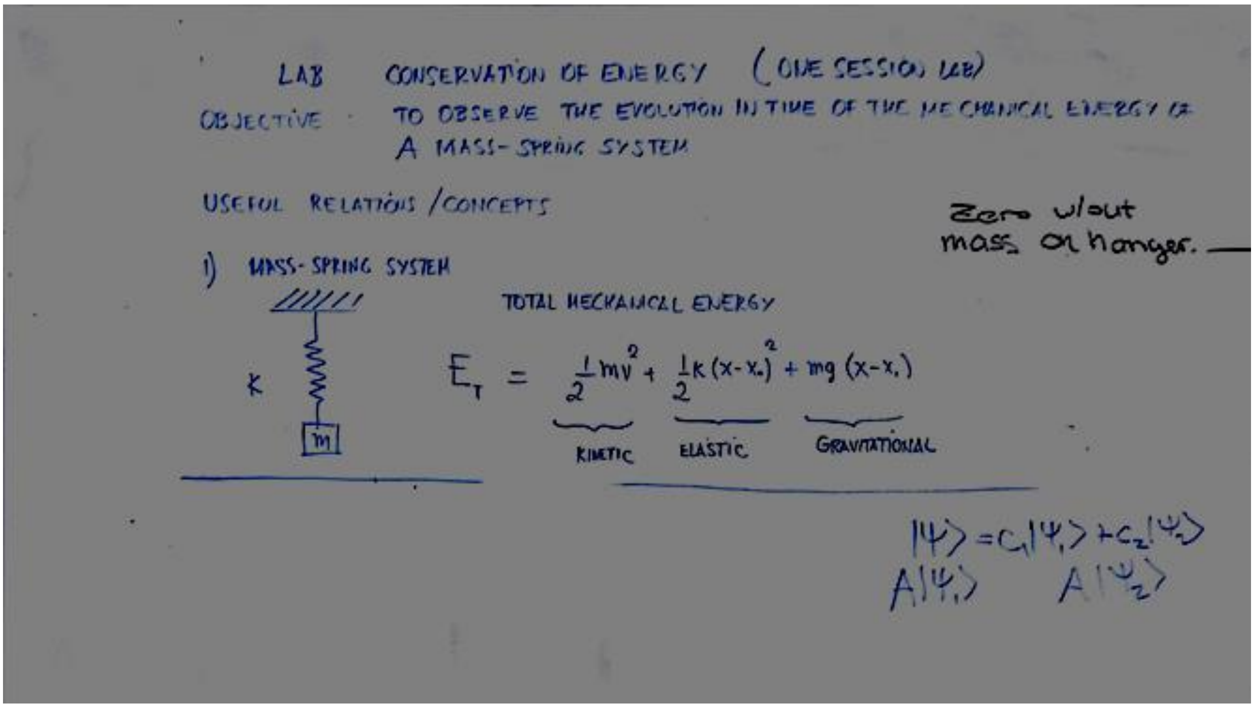
Some students had difficulty creating the trend line for the data in Logger Pro. This is likely a result of a lack of student familiarity with the software. However, some of the trend-line related issues occurred because students were not selecting enough data points. The TAs told students to select a complete cycle within the data for creating a trend line. However, for students that pulled the mass too far down, one oscillation might only contain three or four data points because the motion sensor can only record data at a specific rate. If the mass is oscillating too quickly, then the motion sensor will not collect enough meaningful points within a single oscillation. While this was not much of a problem for the 1111 students, multiple groups in 1110 needed clarification on this point.

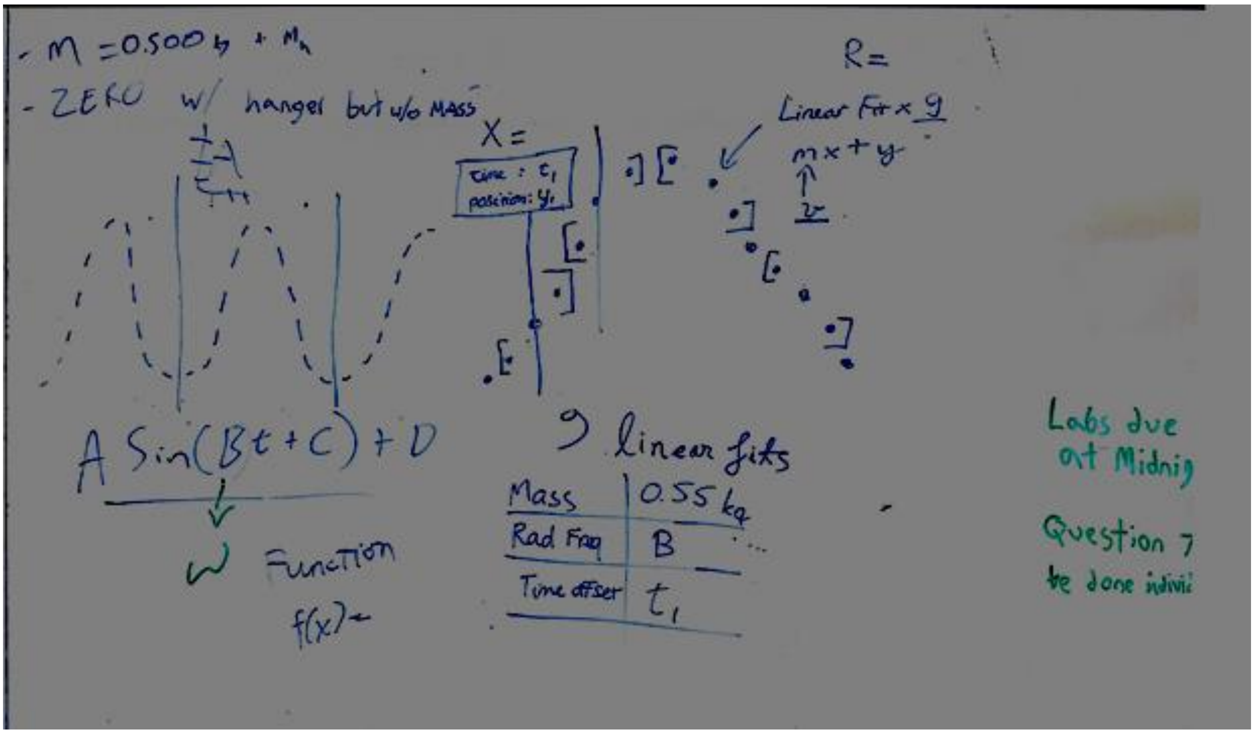
In order to complete these labs, students are required to utilize the formulas for gravitational potential, elastic potential, and kinetic potential energy. In both PH-1110 and PH-1111 labs, these formulas are provided to students on the board. While giving these equations to students certainly helps participants complete the lab on time, we believe that the equations should be removed from the board. This way, students are forced to think more about how to complete the experiment, and are not merely copying the procedure (and answers) off of the board.

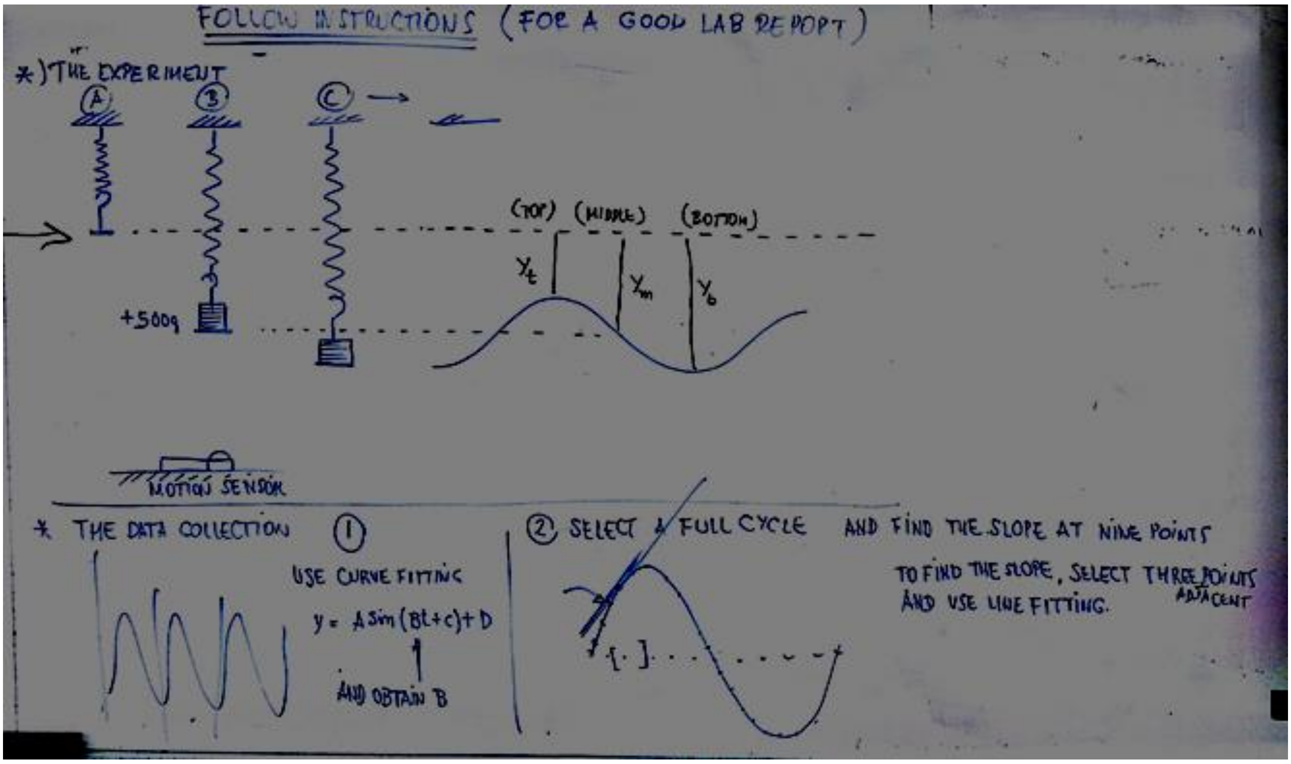
For similar reasons, we think that students should decide for themselves which formula to use when applying a least squares fit to their data within Logger Pro. Therefore, students should be given the formulas for the different types of least-squares fits, but have to decide which one to apply.

Finally, the end of the lab states that “If all has gone well today, you have confirmed that mechanical energy is conserved for a mass on a spring”. There is a question in the worksheet that asks students to report their results, but the answer is given away by this statement in the instructions. We think that this might be nice for the students to reach this conclusion themselves, instead of being told that this is what they should observe.




LAB CONSERVATION OF ENERGY (ONE SESSION LAB)
OBJECTIVE · TO OBSERVE THE EVOLUTION IN TIME OF THE MECHANICAL ENERGY OF A MASS-SPRING SYSTEM
USEFUL RELATIONS /CONCEPTS
Zero w/out mass or hanger.
1) MASS-SPRING SYSTEM
k
m
TOTAL MECHANICAL ENERGY
$E_T = \underbrace{\frac{1}{2}mv^2}_{\text{KINETIC}} + \underbrace{\frac{1}{2}k(x-x_o)^2}_{\text{ELASTIC}} + \underbrace{mg(x-x_o)}_{\text{GRAVITATIONAL}}$
$|\Psi\rangle = c_1|\Psi_1\rangle + c_2|\Psi_2\rangle$
$A|\Psi_1\rangle$ $A|\Psi_2\rangle$


- M = 0.500 kg + M_h
- ZERO w/ hanger but w/o MASS
R =
X =
time : t_1
position: y_1
Linear Fit x 9
mx + y
$A \sin(Bt + C) + D$
ω Function
f(x)
9 linear fits
Mass | 0.55 kg
Rad Freq | B
Time offset | t_1
Labs due at Midnig
Question 7 be done indivi


FOLLOW INSTRUCTIONS (FOR A GOOD LAB REPORT)
*) THE EXPERIMENT
A
B
C
+500g
(TOP) (MIDDLE) (BOTTOM)
Y_t
Y_m
Y_b
MOTION SENSOR
* THE DATA COLLECTION
1
USE CURVE FITTING
y = A sin(Bt+c)+D
AND OBTAIN B
2 SELECT A FULL CYCLE AND FIND THE SLOPE AT NINE POINTS
TO FIND THE SLOPE, SELECT THREE ADJACENT POINTS AND USE LINE FITTING.

6. The Impulse-Momentum Theorem

Procedure

Part I, Theory

• In your notebook or on scratch paper, draw free-body diagrams for a freely falling ball and a force plate resting on a table, and also for the ball and force plate during an impact. Label the forces.

• From your knowledge of kinematics, solve for the expression for the maximum height h_{21} after the first bounce and before the second bounce from the time difference between the first two bounces, $t_2 - t_1$. From your knowledge of kinematics or energy conservation, solve for the expression for the speed v_{21} just after the first bounce and just before the second bounce. Similarly, write the expressions for h_{32} and v_{32}.

• The change in momentum $\Delta\mathbf{p_2}$ due to the second bounce is the mass times the difference between the final and initial velocities, $m(\mathbf{v_{32}} - \mathbf{v_{21}})$. Write the y-component of the change in momentum due to the second bounce, Δp_{y2}. Double check your signs!

When you are satisfied with what you have predicted, open today's worksheet and answer Questions 1 and 2. Check with your lab instructor to confirm that your free-body diagrams and equations are correct. Then move on to Part II.

Part II, Experiment

• Open the Logger Pro file and the worksheet for today. The switch on the force plate should be on the lower range setting, -200/+850 N. Choose a ball that you can drop onto the force plate and record at least five distinct bounces on the F(t) graph. Measure its mass. If you need to put something on the mass balance to keep the ball from rolling off, make sure to subtract its mass. Record the mass of the ball on the worksheet. Also type a short description of the ball.

• Place the ball on the force plate and zero the force using the Zero function on the upper Logger Pro toolbar. Then raise the ball above the plate by about one meter and drop it while acquiring data. Record the times of the first five consecutive bounces in the table in the appropriate boxes of the worksheet.

• Zoom into the data for the second bounce. You'll see a collection of peaks. The entire first peak plus the first half of the first valley is a good measure of the impulse of the impact. Use the Integral function to obtain the impulse J_{y2} of the impact and record it in the J_{y2} box. Repeat the integration for the third and fourth bounces and record J_{y3} and J_{y4}.

• Zoom back out to where your graph shows the five bounces plus the data boxes for the integrations for the second, third, and fourth bounces. Copy and paste this graph into your worksheet, ensuring that the data boxes are readable. You might need to decrease the size of the graph, such that the data boxes consume a larger portion of it.

• Calculate the parameters associated with the green boxes of the table in the worksheet: the ball's speed $v_{i,i-1}$, its change in y-momentum p_{yi}, and the ratio of the change in y-momentum to the integral of force over time p_{yi}/J_{yi}. Then find the average, sample standard deviation (defined in Part II of the friction experiment), and fractional uncertainty (sample standard deviation divided by the average). Your fractional uncertainty should be less than 0.100.

• Check that you filled in all of the square brackets in the table with the correct units.

• The last question on the lab report asks you to report your result in standard form and, in your own words, discuss what you expected in comparison to your experimental result. Mention possible reasons for any difference.

If all has gone well today, you will have verified that the change in momentum is equal (or close) to the integral of the force over time, that is, the impulse-momentum theorem is true.

Worksheet

Name and section number:
Partner's name and section number:

1. Make free-body diagrams of the ball and the force plate just before and during an impact. Label the forces. Ignore air resistance. You may enlarge the drawing canvas and move captions.

Ball and force plate just before an impact

Ball and force plate during an impact

2. Derive the expression for the maximum height h_{21} after the first bounce and before the second bounce from the time difference between the first two bounces, $t_2 - t_1$. Derive the speed just after the first bounce and just before the second bounce, v_{21}. Similarly, write the expressions for h_{32} and v_{32}. Also, write the y-component of the change in momentum, Δp_{y2}.

h_{21} =
v_{21} =

h_{32} =
v_{32} =
Δp_{y2} =

3. Paste your raw data here. Data boxes for the second, third, and fourth bounces should show the integral of the first peak and half valley in the set of peaks corresponding to one bounce.

4. Enter your raw data into the yellow boxes and your calculated data in the green boxes. Enter the units in the square brackets. All data in the table should have at least four significant figures.

Time []		Mass =	[]	Description:					
t_1 =		Speed []		Δp_{yi} []		J_{yi} []		$\Delta p_{yi}/J_{yi}$	
t_2 =		v_{21} =		Δp_{y2} =		J_{y2} =		$\Delta p_{y2}/J_{y2}$ =	
t_3 =		v_{32} =		Δp_{y3} =		J_{y3} =		$\Delta p_{y3}/J_{y3}$ =	
t_4 =		v_{43} =		Δp_{y4} =		J_{y4} =		$\Delta p_{y4}/J_{y4}$ =	

t_5 =		v_{54} =	

Average:	
Std dev:	
Sd/ave:	

5. *Individually* report your result in standard form. Discuss what you expected in comparison with your experimental result. Mention possible reasons for any difference.

Our Analysis of this Laboratory

This lab explores the relationship between impulse and momentum. The experiment involves bouncing a tennis ball on a force plate to observe the impulse of the impact. That impulse is then compared to the change in momentum of the tennis ball to discover the relationship between the two. The students are very familiar with Logger Pro by now, so the software didn't slow down this lab at all. The TAs commented that this was one of the better experiments in the PH1110 labs.

One of the reasons that this lab ran so smoothly could be that the instructions lead the students to a conclusion. A lab running this smoothly isn't always a good thing. If the students just follow the instructions until they prove a theorem then what do they learn? The introduction of the lab instructions introduces the impulse-momentum theorem: that the impulse is equal to the change in momentum. The lab should be set up for the students to explore whether or not that theorem is true. Instead the students follow cookie cutter instructions to reach a conclusion that is stated at the end of the lab instructions.

"If all has gone well today, you will have verified that the change in momentum is equal (or close) to the integral of the force over time, that is, the impulse-momentum theorem is true."

The students cannot draw their own conclusion about the theorem if the correct observation is given to them. The labs should not be a recipe, but more of a general guideline as to what the experiment is seeking to prove. The students should figure out what to do with the data they have collected instead of being told what to do with their data. We suggest omitting the last sentence of the instructions, and making the instructions more vague. Particularly when it comes to the data crunching, that should be on the students.

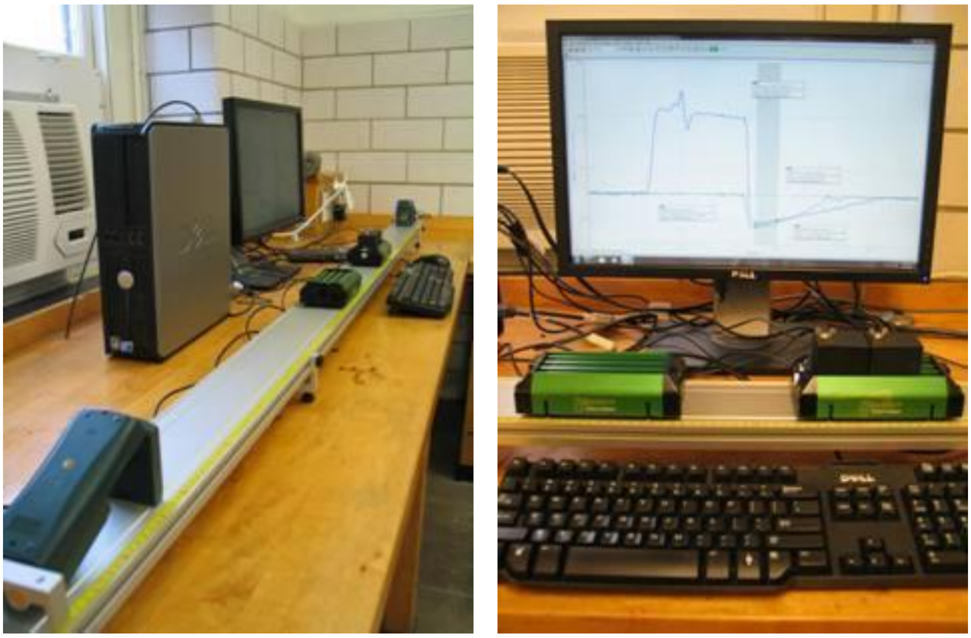
7. Work-Energy and Momentum

Procedure

Overview

Today you are going to record the speeds of two carts before and after a collision. You will do this twice, once with one cart with a nearly elastic plunger extended towards the other cart, and once with shock-absorbing material placed at the points where they hit each other. You will calculate the carts' kinetic energies and momenta and observe how they change.

There are three parts to this experiment. Part I concerns theory, Part II, data collection, and Part III, analysis. Ideally, you have tried Part I before arriving in lab so that you will have plenty of time to complete the worksheet. If not, start with Part II. Collect the data for Question 3 and the yellow boxes of Question 4, then return to Part I.



Far and near views of today's equipment and example data.

Part I, Theory

• In your notebook or on a piece of scratch paper, sketch free-body diagrams of a cart traveling at constant velocity on a horizontal track, a cart at rest on a horizontal track, and the two carts when they collide. Label the forces. Friction is negligible.

• Write out the work-energy theorem and the principle of conservation of momentum in words and equations.

When you are satisfied, open the worksheet and answer Questions 1 and 2. Check with your lab instructor to confirm that your free-body diagrams, statements, and equations are correct. Then move on to Part II.

Part II, Data Collection

• You will use two carts and two motion detectors today. Place a motion detector at each end of the track facing the middle of the track. One cart should have a plunger; they each should have two

Velcro tabs on one bumper. One cart should have one or two masses attached. The cart without the mass(es) attached should be on the left (Cart A). The track should be level, such that when you place the carts on the track at rest, they stay at rest. It doesn't matter if you start with the plunger extended or retracted. The plunger (or Velcro tabs) should face the other cart. Open today's Logger Pro file.

• When a mass balance is free, determine the masses of your carts. Record the masses in the yellow boxes of the tables, with the units in square brackets. For the more massive cart, you will have to hang additional mass on the balance in order to obtain an accurate value. Next to "Collision:" on the tables of the worksheet, type a short description of which collision the table will be, e.g. "with plunger" or "with Velcro."

• With Cart A (without masses) at about 20 cm in front of the left-hand sensor and Cart B (with masses) in the center of the track, gently give Cart A a momentary push while acquiring velocity data. Please prevent Cart B from crashing into the right-hand motion detector.

• You shall see sudden changes in the v(t) traces that represent the change in velocities during the collision. Measure the x-components of the velocities of Carts A and B just before and just after the collision. Use the statistics function ("STAT") on the upper toolbar, setting the brackets around ten to fifteen datum points. Record the mean values of the x-components of the velocities in the yellow boxes of the table, where, for example, v_{Ai} is the initial x-velocity of Cart A and v_{Bf} is the final x-velocity of Cart B. Indicate the direction of motion with the convention that motion to the right is positive. Paste your graph into the appropriate box on the worksheet such that its width is roughly half the width of the box and the data and data boxes are readable.

• If your first data acquisition was with the plunger extended, depress it now, and vice-versa if your first run was with the plunger retracted, such that the Velcro kept the carts together after the collision. Directly above the plunger is a release pin for extension and an oval catch to hold down as you push the plunger in.

• Repeat the data collection, and then move on to Part III, Analysis.

Part III, Analysis

• At this point, all the yellow boxes in the tables of the worksheet should be full. Now is a good time to put all of the units of your data into the square brackets.

• In the following, remember that to calculate a change, you subtract the initial value from the final value, e.g., $\Delta K = K_f - K_i$. Lower-case variables refer to an individual cart and upper-case ones to both carts.

• Calculate the kinetic energies of the individual carts before and after the collision and place your values into the green boxes in the second column. At the top of the third column, calculate the change in kinetic energy of the individual carts. Then calculate the initial and final kinetic energies of the two carts summed together, followed by the change in kinetic energy of the two carts, and finally divide the change in kinetic energy by the initial kinetic energy (the proportional change in kinetic energy).

• The fourth and fifth columns for the momentum follow the same pattern as the second and third columns for kinetic energy. The fourth column contains the x-components of the momenta for the individual carts just before and just after the collision. The fifth column is for the values of the momentum changes for the individual carts, the total initial and final momenta, the change in total momentum, and the change divided by the initial momentum.

- There are four fractional changes on your worksheet. Two should be greater than 0.100, and two should be less. Make sure you understand why before you answer the individual questions on the worksheet.

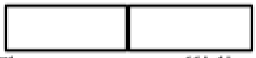
If all has gone well today, you will have demonstrated that independent of the materials involved one entity (kinetic energy or momentum) is conserved (i.e. remains the same) during a collision, and the other one is not. The other entity will be very different depending on the kind of collision.

Worksheet

Name and section number:
Partner's name and section number:

1. Sketch free-body diagrams of a frictionless cart moving at constant velocity, a cart at rest, and two carts colliding. Label the forces. You may enlarge the drawing canvas and move captions.


A cart at constant velocity, a cart at rest


The two carts colliding

2. Write the work-energy theorem and conservation of momentum in words and equations.

3. Paste your two graphs into the box below, with data and data boxes legible.
a) b)

4. Enter your raw data into the yellow boxes and your calculated data in the green boxes. Enter the units in the square brackets. All data in the table should have at least four significant figures.

m_A=	[]	m_B =	[]	Collision :					
x-Velocity []		Kinetic energy []				x-Momentum []			
v_{Ai} =		k_{Ai} =		Δk_A =		p_{Ai} =		Δp_A =	
v_{Af} =		k_{Af} =		Δk_B =		p_{Af} =		Δp_B =	
v_{Bi} =		k_{Bi} =		K_i =		p_{Bi} =		P_i =	
v_{Bf} =		k_{Bf} =		K_f =		p_{Bf} =		P_f =	
				ΔK =				ΔP =	
				$\Delta K/K_i$ =				$\Delta P/P_i$ =	

m_A=	[]	m_B =	[]	Collision :					
x-Velocity []		Kinetic energy []				x-Momentum []			
v_{Ai} =		k_{Ai} =		Δk_A =		p_{Ai} =		Δp_A =	

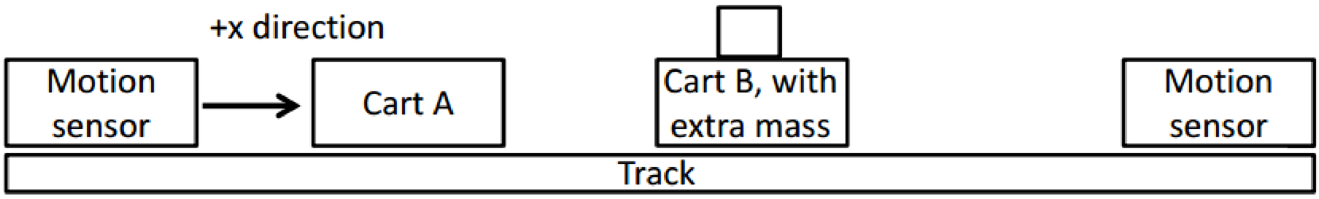
v_{Af} =		k_{Af} =		Δk_B =		p_{Af} =		Δp_B =	
v_{Bi} =		k_{Bi} =		K_i =		p_{Bi} =		P_i =	
v_{Bf} =		k_{Bf} =		K_f =		p_{Bf} =		P_f =	
				ΔK =				ΔP =	
				$\Delta K/K_i$ =				$\Delta P/P_i$ =	

5. *In your own words*, state which data pair in the tables should be equal and opposite. Is your statement consistent with your free-body diagrams of the collision? Should it be?

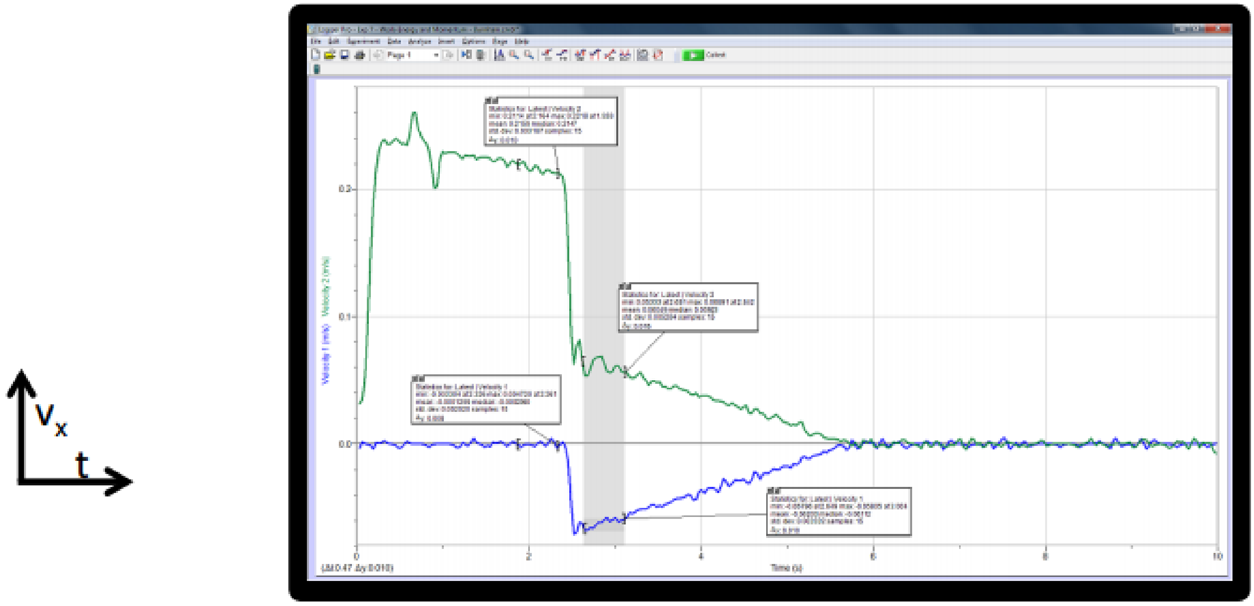
6. *In your own words*, discuss why the $\Delta K/K_i$ values are very different for the two experiments, yet the $\Delta P/P_i$ values remain approximately the same. Where does the "lost" energy go? How does work get done on the carts?

Our Analysis of this Laboratory

The Work-Energy and Momentum Lab focuses on observing the change in kinetic energy and momentum during elastic and inelastic collisions. To complete this lab, students are given a track on a level surface, two carts, and two motion sensors. One of the two carts has additional mass placed on top of it. Additionally, one cart has a plunger that protrudes from the bumper and can be extended or retracted. When the plunger is extended, the two carts will bounce off of one another. Because both carts have a strip of Velcro attached to the bumper. When the bumper is retracted and the carts are allowed to collide, the Velcro strips will make the carts stick together. The carts also have magnets in them, to help the carts stick.



This lab, like many other experiments in this course, reveals too much information about the intended results to students. For instance, the last sentence of the procedure states, "you will have demonstrated that independent of the materials involved one entity (kinetic energy or momentum) is conserved (i.e. remains the same) during a collision, and the other one is not. The other entity will be very different depending on the kind of collision". The same problem exists in the worksheet. Question 6 states, "*In your own words*, discuss why the $\Delta K/K_i$ values are very different for the two experiments, yet the $\Delta P/P_i$ values remain approximately the same. Where does the "lost" energy go? How does work get done on the carts?" Finally, in the "overview" section of the procedure, students are provided a photograph of collected data. Screenshots of data should not be provided to students because it gives students something to measure their intermediate results against and defeats the purpose of the experiment.

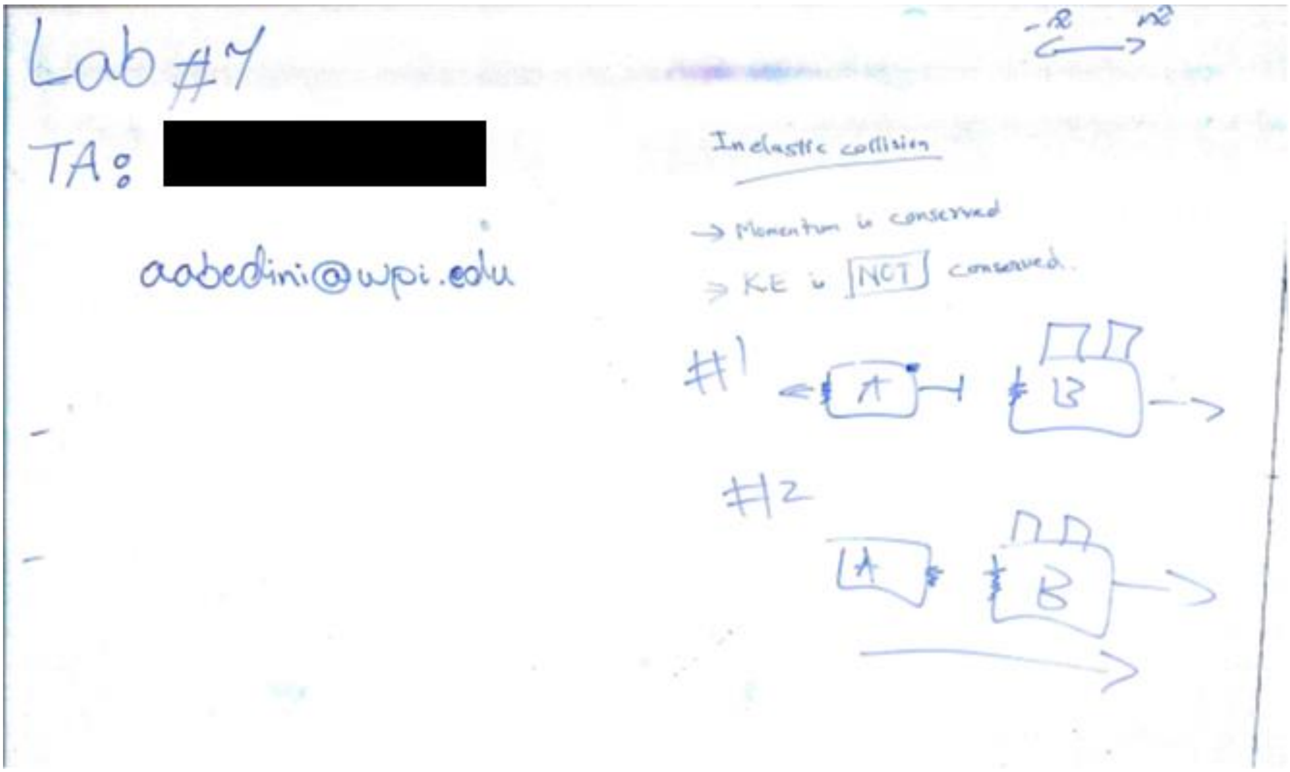


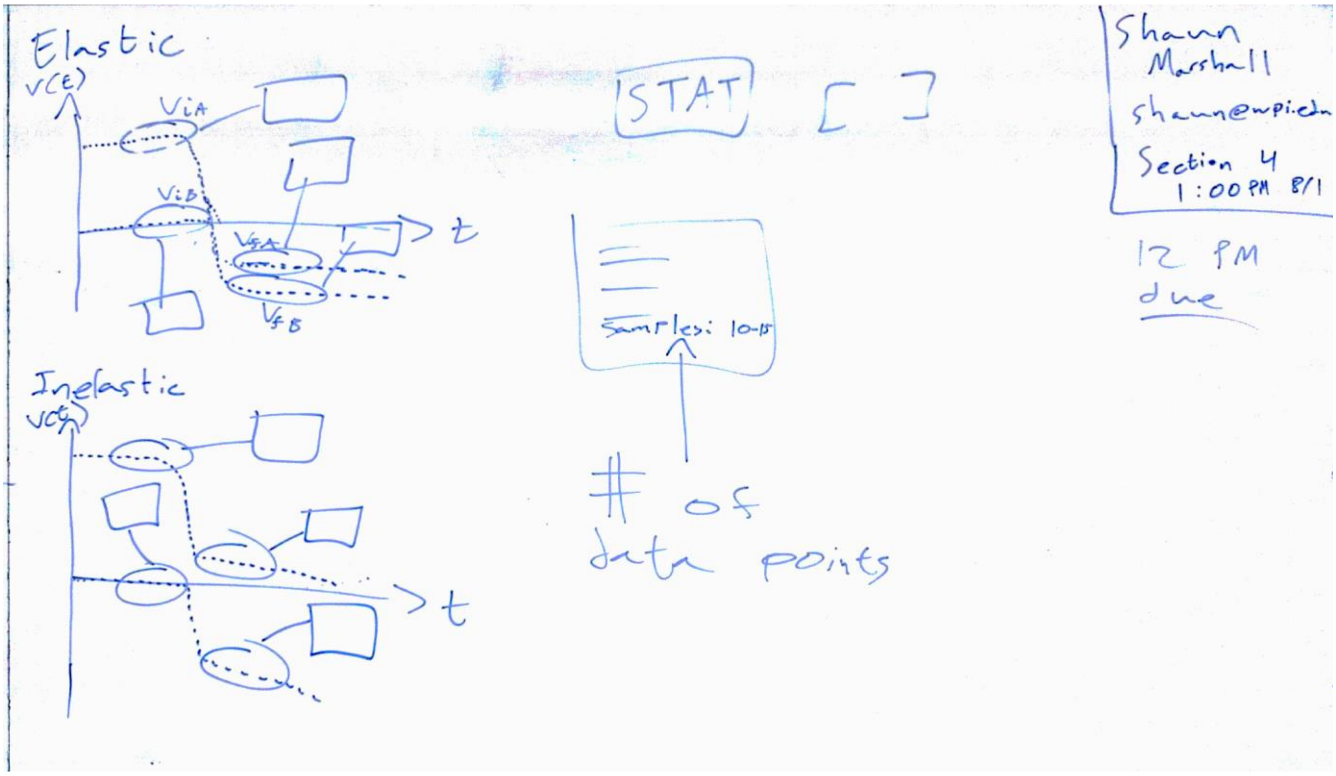
The major flaw with this lab is that students are told that one collision will result in conservation and the other should not – and are then told to verify that their results are in agreement. Instead, students should instead perform the experiment, and then use the results to draw their own conclusions about conservation.

There were also a few minor problems with the equipment during this experiment. For problem 4 of the worksheet, students are supposed to fill out a data table with collision data. One field in the data table is initial velocity. This is obtained by analyzing the data that is acquired through the use of the Logger Pro motion sensors. Since the sensors are not perfect, Logger Pro will detect a small initial velocity even though Cart B is completely stationary. The TA warned students to ignore this inaccuracy and enter 0 m/s into the data table instead. However, while it is true that Cart B is visibly

stationary, students should not be encouraged to alter the data that the motion sensors produces because these small inaccuracies are inherently present in all values measured with the motion sensor. Altering only some of the data introduces more inaccuracy than it fixes.
Additionally, two groups seemed to have difficulty determining which portions of their data was useful. These students were selecting the meaningless noise at the beginning and end of their results in addition to their actual data. Including this meaningless data caused some students to have slightly skewed values when using any of Logger Pro's analysis tools. In Lab #0 (or any early lab in the course where there is extra time), it may help to put a greater emphasis on teaching students how to decide if data is relevant or not.

The Work-Energy and Momentum lab is an extremely educational lab and provides students with a real understanding of the underlying physics during a collision of two objects. However, the educational value of the lab is greatly diminished because students are not forced to conduct a traditional experiment. Instead, they are provided the intended results, and merely told to verify that their data matches the pre-provided conclusion.




Elastic
v(t)
ViA
ViB
VfA
VfB
t
Inelastic
v(t)
t
STAT
[ ]
Samples: 10-15
# of data points
Shawn Marshall
shawn@wpi.edu
Section 4
1:00 PM 8/1
12 PM due

8. Static Equilibrium

Procedure

Overview

The purpose of this experiment is for you to verify the conditions for equilibrium of an extended object. This experiment will be carried out on a force table, and you shall be making all of the measurements by hand, rather than with computer assistance. The sophisticated extended object is a Popsicle stick.

You will collect data and analyze two cases. The first case is for rotational equilibrium only, for which you shall apply two forces to the object by means of two strings, two pulleys, and two mass hangers with masses. Here, the object is held in place by a pin in the center of the table that passes through a hole in the object. The second case is for both rotational and translational equilibrium, for which you shall have removed the pin. You shall apply a third string force such that the object rests at the center of the force table.

There is a short theory question at the beginning of the worksheet that you are encouraged to answer before you go to lab.

Force table with pin, extended object, pulleys, mass hangers, and masses

Part I, Rotational equilibrium

• Ensure that there is a vertical pin in the center of your force table. Place the pin through the largest of the five holes in the stick. Hang 100 g from one of the four threads tied to the stick, and 200 g from another. The threads should run over the pulleys and the points of the pulleys should line up with the direction of the threads. Choose positions for the pulleys such that the threads make at least 15^{o} angles with the long axis of the stick.

• Open the worksheet for today. Complete the sketch in Question 2 by moving the vectors and symbols to reflect the forces on the stick from the threads. Move the origin of the coordinate system to correspond to the position of the pin.

• Record your raw data in the yellow cells of the first table. Using the protractor, measure the distances (to the nearest millimeter) between the pin and the holes where your two threads are attached. These are the magnitudes of your position vectors. Measure the angle (to the nearest half of a degree) that the threads make with the direction of your position vectors. Measure the two masses (with hangers, to the nearest tenth of a gram) using a mass balance.

• Fill in the first table: Calculate the force magnitudes, force vectors, torque magnitudes, and torque vectors. Remember that positive torques are ones that would cause counter-clockwise motion. Sum the torque magnitudes and torques. Calculate the fractional error by dividing the sum of the torques by the sum of their magnitudes. If the fractional error is greater than 0.099, redo your calculations or repeat the experiment. Don't forget to note your units in the square brackets at the top of each column.

Part II, Rotational and translational equilibrium

• Choose one of the two remaining threads and pull on it, varying the force and angle until there seems to be little force on the central pin. Put a third hanger on this thread, run the thread over the third pulley, and add mass to it until the force on the pin seems to be zero.

• Check that the points of the pulleys are aligned with the directions of the threads, and that all of your angles with respect to the long axis of the stick are greater than 15°. Remove the pin. If you have successfully found the conditions for rotational and translational equilibrium, the stick will not move. Just in case friction between the threads and pulleys might be limiting the stick's motion, tap on the force table to see if the stick changes its position from the center of the table. Adjust masses and angles if necessary.

• Repeat the procedures for Questions 2 and 3 for Questions 4 and 5 of the worksheet. In comparison to the first set of questions, the second set includes a third force (and torque), and you are asked for the sum of the force magnitudes, forces, and relative error in force. This time, you may place the origin where you choose, but make sure that both the data in the table and the coordinates in the sketch are consistent with your choice. If you start to run out of time, collect the raw data (yellow cells) and finish your work later. If any of the fractional error components are greater than 0.099, redo your calculations or repeat the experiment. Don't forget to note your units in the square brackets at the top of each column.

• Individually answer the last question about the force of the pin on the stick for the first case, for which you considered only rotational equilibrium. Think about if translational equilibrium still applies.

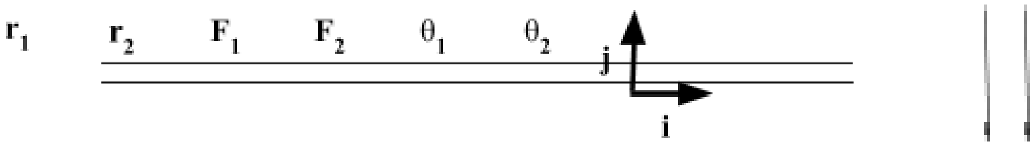
If all has gone well today, you will have confirmed that the sums of the forces and torques are equal to zero in equilibrium.

Worksheet

Name and section number:
Partner's name and section number:

1. What are the conditions for equilibrium, expressed in both words and equations? The title "Static Equilibrium" implies that there is be another kind of equilibrium. Name and describe it.

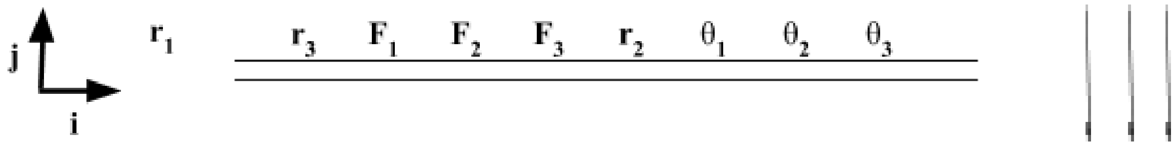
2. For the case with the pin in place, sketch the two horizontal string forces acting on the extended object. Show their correct orientations, relative magnitudes, and relative positions. The coordinates, object, symbols, and vectors are provided for your convenience. Move the coordinate system to the location of the pin.



3. Fill in this table to see if you have met the condition for rotational equilibrium.

i	m_i [ ]	$\|\mathbf{F}_i\|$ [ ]	θ_i [ ]	$\mathbf{F}_i$ [ ]	$\mathbf{r}_i$ [ ]	$\|\boldsymbol{\tau}_i\|$ [ ]	$\boldsymbol{\tau}_i$ [ ]
1				**i j**	**i**		**k**
2				**i j**	**i**		**k**
					$\sum\|\boldsymbol{\tau}_i\|, \sum\boldsymbol{\tau}_i$ =		**k**
						$\sum\boldsymbol{\tau}_i/\sum\|\boldsymbol{\tau}_i\|$ =	**k**

4. For the case of no pin, sketch the three forces, in the same way as for Question 2.



5. Fill this in to see if you have met the conditions for rotational and translational equilibrium.

i	m_i [ ]	$\|\mathbf{F}_i\|$ [ ]	θ_i [ ]	$\mathbf{F}_i$ [ ]	$\mathbf{r}_i$ [ ]	$\|\boldsymbol{\tau}_i\|$ [ ]	$\boldsymbol{\tau}_i$ [ ]
1				**i j**	**i**		**k**
2				**i j**	**i**		**k**
3				**i j**	**i**		**k**
	$\sum\|\mathbf{F}_i\|$ =		$\sum\mathbf{F}_i$ =	**i j**	$\sum\|\boldsymbol{\tau}_i\|, \sum\boldsymbol{\tau}_i$ =		**k**
			$\sum\mathbf{F}_i/\sum\|\mathbf{F}_i\|$ =	**i j**		$\sum\boldsymbol{\tau}_i/\sum\|\boldsymbol{\tau}_i\|$ =	**k**

6. *Individually,* visually estimate the force from the pin on the extended object and place a third red vector, properly scaled and oriented, on the sketch in Question 2 to reflect your thinking. There is no need to label the red vector, although you should have labeled the other vectors with the given symbols. Here is a red vector. In the box below, describe the role of the pin force.

Our Analysis of this Laboratory

In this lab, students are tasked with learning about forces, torque, and static equilibrium. To conduct the experiment, each lab group is provided with a force table, a set of mass hangers, and a popsicle stick. By attaching weights to the popsicle stick and hanging the masses off of the force table, students are expected to conclude that the sum of forces and torques are equal to zero when the popsicle stick is placed in rotational equilibrium.

Students attempt to create rotational equilibrium followed by translational equilibrium using a system of pulleys and hanging masses. Calculations and measurements are done by hand as opposed to the usual computerized results (an interesting aspect of this lab).

Like all other 1110 labs, a lab overview page is included with the instructions. In the center of this page is a photograph of the force table and weights. Unlike some of the photographs included in the overview sections of previous labs, this photograph serves as an excellent reference to students and does not reveal any of the expected outcomes of the experiment. Furthermore, we appreciated that in this lab, students are required to make calculations on paper. The overview states, “This experiment will be carried out on a force table, and you shall be making all of the measurements by hand, rather than with computer assistance”.

However, there is still much room for improvement in this lab. Because students are only given an hour to conduct this experiment, few were able to finish the experiment on time. In the lab section that we attended, only one group left before the hour was up. If possible, spreading this experiment out over the course of two lab periods would help immensely. Doing so would not only allow TAs to spend more time helping students, but would also help ensure that students have collected all of the necessary data before leaving the lab.

Additionally, students seemed to have a difficult time performing cross product calculations. The cross product is not taught in lecture, so there might have been students who have never done a cross product before. While the TAs were able to help with some of these issues, perhaps providing students with additional practice before coming to lab would help more students finish on time.

Moreover, at the end of part I, the instructions state, “Calculate the fractional error by dividing the sum of the torques by the sum of their magnitudes. If the fractional error is greater than 0.099, redo your calculations or repeat the experiment.” This statement should be removed. There is no “experiment” if students are told to repeat the procedure until their data is deemed ‘correct’.

In a similar vein, this lab, like many other PH-1110/1111 labs, reveals the expected outcome to students in the end of the procedure instructions. The last sentence of Part II reads, "If all has gone well today, you will have confirmed that the sums of the forces and torques are equal to zero in equilibrium". Instead, this sentence should be removed and a question should be added to the worksheet that asks students to draw their own conclusions about the sum of the forces acting on the popsicle stick.

Where many other PH-1110/1111 labs rely on sophisticated software and spreadsheets to help students make calculations, this lab is excellent in the way that it requires students to make the calculations themselves. As a consequence, however, most students were not able to complete the experiment on time. This lab does an excellent job teaching students about rotational equilibrium, but the instructions make it hard for students to analyze their own data and learn from their own mistakes. By removing the unnecessary statements mentioned above, the educational value of this experiment could be greatly increased.

9. Similarities of Translational and Rotational Kinematics

Procedure

Overview

The equations for rotational kinematics might seem unfamiliar, but they are closely related to those for the more familiar translational kinematics. The purpose of this experiment is to help you appreciate their similarities. We return to the usual cart, track, and motion sensor, although this time the track is steeply sloped and connected to a vertically hanging set of masses via a string that passes over a pulley. As the pulley turns, its rotation is sensed and sent to the computer. We assume that the string does not slip on the pulley, but it is up to you to verify our assumption. You will also see a meter-long thread at your lab station that will be used to determine the radius of the largest of the three pulleys on the rotary sensor.

You will predict the expected translational acceleration from Newton's Second Law, then experimentally determine the acceleration in four different ways, two from translation and two from rotation. If all ways are equivalent, all five values for acceleration should be the same.

There are three parts to this experiment. Part I concerns theory, Part II, experimental preparations, and Part III, data collection and analysis. Ideally, you have tried Part I before arriving in lab so that you will have plenty of time to complete the worksheet. If not, start with Part II. Collect the data for Question 4 and the yellow boxes of Question 5, then return to Part I.

Far and near views of today's equipment and data

Part I, Theory

• In your notebook or on a piece of paper, sketch free-body diagrams for the masses on the hanger and the cart. (You might need to look again at the experimental setup in the picture in the Overview.) Friction is negligible at this steep angle. (Do you understand why?) The acceleration for the cart will be up the slope.

• Sum the forces in the direction of travel and predict the acceleration based on the mass of the hanger, m_h, the mass of the cart, m_c, gravitational acceleration, g, and the angle of the track up from the horizontal, φ.

• Write out the equations for translational and rotational kinematics (x(t), θ(t), v(t), and ω(t)). Also write the equations connecting x and θ, v and ω, and a and α. The latter are based on the "no-slip" condition that the string will not slip on the pulley (radius r).

• When you are satisfied, open the worksheet for today and answer Questions 1-3. Ask your lab instructor if they are correct, then move on to Part II.

Part II, Experimental preparations

• Measure the angle of the track using the meter-stick. It is easiest to measure the height H of the track up from the floor at some convenient point along the track, then the length L of the track down to the floor, and then use your knowledge of geometry to calculate the angle φ of the track up from the horizontal. Enter these values into the table of Question 5.

• Place the cart on the track with the string connected to the mass hanger, with the string running over the largest of the three pulleys on the rotation sensor, and with the translation sensor in position at the bottom of the track. Place mass on the mass hanger to the nearest 1-g value so that the cart/mass-hanger system is in equilibrium. Place an extra 20-g mass on the mass hanger so that the cart accelerates up the incline and the hanger comes to rest on the floor.

• If the mass balance is free, measure the masses of the cart, m_c, and the masses plus the hanger, m_h, using the mass balance. Enter the values into the table. If the mass balance is not free, skip to the next step, then measure the masses afterwards.

• Measure the largest pulley's radius. Wrap the loop on one end of the meter-long black thread around the post of the position sensor, and run the thread around the circumference of the largest pulley five or six times. There's a notch in the side of the pulley that makes it easy to count the number of times that you run the thread around. After you have an integral number of revolutions, grab the thread as close as you can to the pulley, at both the beginning and end of its travel around the pulley. Remove the thread, then stretch it out and measure its length along the meter stick to the nearest millimeter. Record this value of S in the table of Question 5 of your worksheet, as well as the number of times that the thread went around the pulley's circumference, n.

• Return the cart to the track with the string connected to the mass hanger, with the string running over the largest of the three pulleys on the rotation sensor, and with the translation sensor in position at the bottom of the track. Zero the two sensors: the rotational sensor associated with the pulley at the top of the track, and the translational sensor at the bottom of the track.

• Starting with the cart near the top of the incline, practice giving it a push down the incline so that it coasts at least half a meter down before coming momentarily to rest and accelerating back up the incline. (Be sure to avoid crashes.)

Part III, Data collection and analysis

• Open the Logger Pro file for today. Record the results of the subsequent motion after a push down the track until you are satisfied that you have a good set of four graphs: x, v, θ, and ω, all vs.

t. The shapes of the curves should be parabolic or linear.

• As in the past, fit straight lines using the Linear Fit routine to the v(t) and ω(t) graphs to get a value for the accelerations of the cart, a_v and α_ω. Define a range covering most of the x(t) parabola. Open the Curve Fit routine. Choose the At^2+Bt+C option for the General Equation, and click the Try Fit button, then OK. Note that the “A” in the Logger Pro equation is not divided by 2, whereas the “a” (or “α”) in the kinematics expression for x(t) is. These are the accelerations a_x and α_θ. Enter the four experimentally determined values of acceleration into the table in Question 5 of the worksheet. All the yellow boxes of the table of Question 5 should now be filled.

• Position the data boxes on your graphs and size the graphs such that the data themselves and the contents of the data boxes can be easily read. Copy and paste the graphs into Question 4 of your worksheet.

• Use the expression that you found for Question 2 to find the acceleration as predicted by Newton, a_N.

• With your knowledge of the relationships among the translational and rotational variables and assuming that the “no-slip” condition applies, calculate the translational acceleration a_ω from the rotational acceleration α_ω, and likewise a_θ from α_θ. Enter these into the table.

• You should now have five different values for translational acceleration in your table, one predicted from Newton’s Second Law, two from the direct translational measurements, and two indirectly from the rotational measurements. They are the ones in the bold cells in the worksheet: a_N, a_v, a_ω, a_x, and a_θ. Average them, find their standard deviation and their fractional uncertainty (standard deviation divided by the average), and enter these values into the table. Your fractional uncertainty should be less than 0.100.

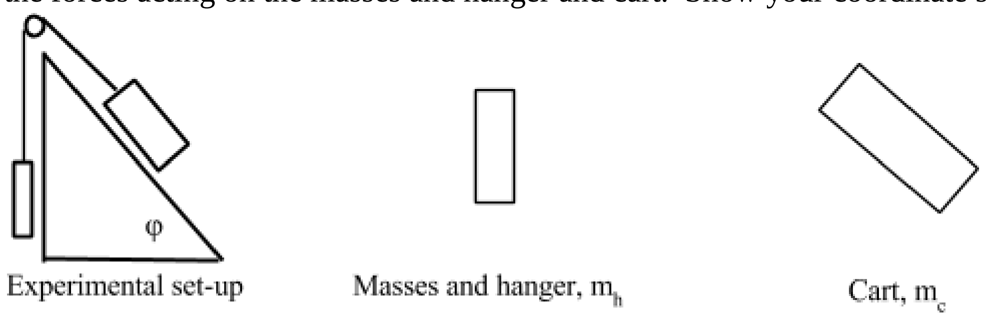
• There remain two questions on the worksheet for you each to answer individually.

If all has gone well today, you have found the same value for acceleration in multiple ways and have seen how rotational motion can be similar to translational motion.

Worksheet

Name and section number:
Partner’s name and section number:

1. Sketch the forces acting on the masses and hanger and cart. Show your coordinate systems.



2. Apply Newton's Second Law to the diagrams above and solve for the translational acceleration as calculated by Newton, a_N. Show your work.

3. Type the kinematical equations for x, θ, v, and ω. Also type the equations relating x and θ, v and ω, and a and α, given the "no-slip" condition that the string does not slip on the pulley.

4. Copy and paste your raw data here, with the data and data boxes legible.

a) b)

c) d)

5. Fill in this table. If you are rushed for time, at least fill the yellow boxes with your raw data.

H []	L []	φ []	m_h []	m_c []	S []	n	r []
a_N []	a_v []	α_ω []	a_x []	α_Θ []		**Acceleration results**	
						Average:	
		a_ω []		a_Θ []		Std Dev:	
						SD/Ave:	

6. *Individually* report your result for average acceleration in standard form. Comment on the equivalence of the different ways of determining acceleration in this experiment.

7. Use two pairs of acceleration results to find two alternative values for r. Find them. Compare them to the value measured by the string. Has the "no-slip" condition been met? Explain.

Our Analysis of this Laboratory

The Similarities of Translational and Rotational Kinematics Lab focuses on:

1. Predicting the translational acceleration of the mass-hanger-cart system
2. Measuring the translational and rotational accelerations
3. Converting the rotational accelerations to translational accelerations

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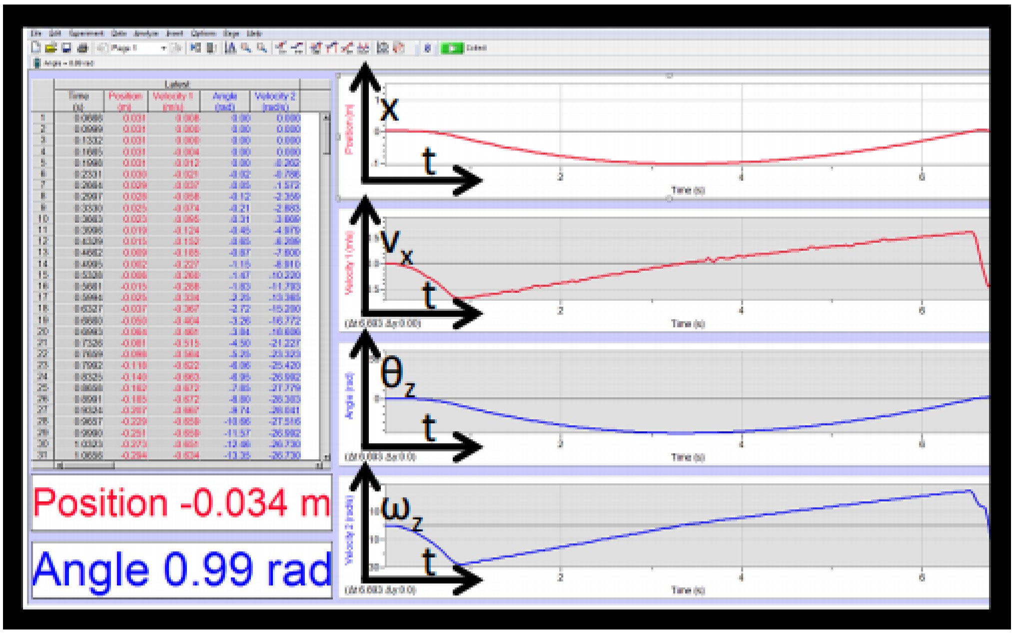
In this lab, students are given a sloped track, a mass hanger, a cart, and a motion sensor. Students are instructed to place the cart on the track and add weight to the mass hanger. By pushing the cart down the track and using the motion sensor to collect data, students are asked to make observations about translational and rotational acceleration.

Before starting the experiment, the TAs warned students that their v(t) and ω(t) graphs may appear upside-down on some computers and right-side up on others. The orientation of the graphs is affected by the orientation of the collection sensor. While the orientation of the graphs will not negatively affect any results, it may be helpful to include this warning in the instructions. Included with this lab is a "preview" page which details the main focus of the lab. This section of the procedure contains an excellent diagram of the experiment setup. Many previous labs would benefit from a similar picture. However, farther down the page is a screenshot of the Logger Pro file, which depicts sample data for the measured x, v, θ, and ω values. Screenshots of data should be removed because it removes the need for students to analyze and understand their own data.



On a related note, part III of the experiment tells students that after making data collection with Logger Pro, "*The shapes of the curves should be parabolic or linear. As in the past, fit straight lines using the Linear Fit routine to the v(t) and ω(t) graphs to get a value for the accelerations of the cart, av and αω*". Students should not be told what their data should look like or how to apply a least squares fit. The decision on how to interpret the data should be up to the discretion of the students conducting the experiment.

We noticed a few more issues with the instructions in part II. For example, the instructions tell students to use trigonometry to calculate the angle of the track. Three lab groups had trouble with this. At its highest point, the track is much taller than the meter stick that students are provided. These groups had trouble calculating the angle of the track because they attempted to measure the entire height and the entire length of the track. Instead, picking a point along the track (instead of measuring from the corners of the triangle) allows for much easier measurements. The instructions attempt to explain this, but these students either did not follow the directions, or had trouble understanding the lab procedure's suggestion:

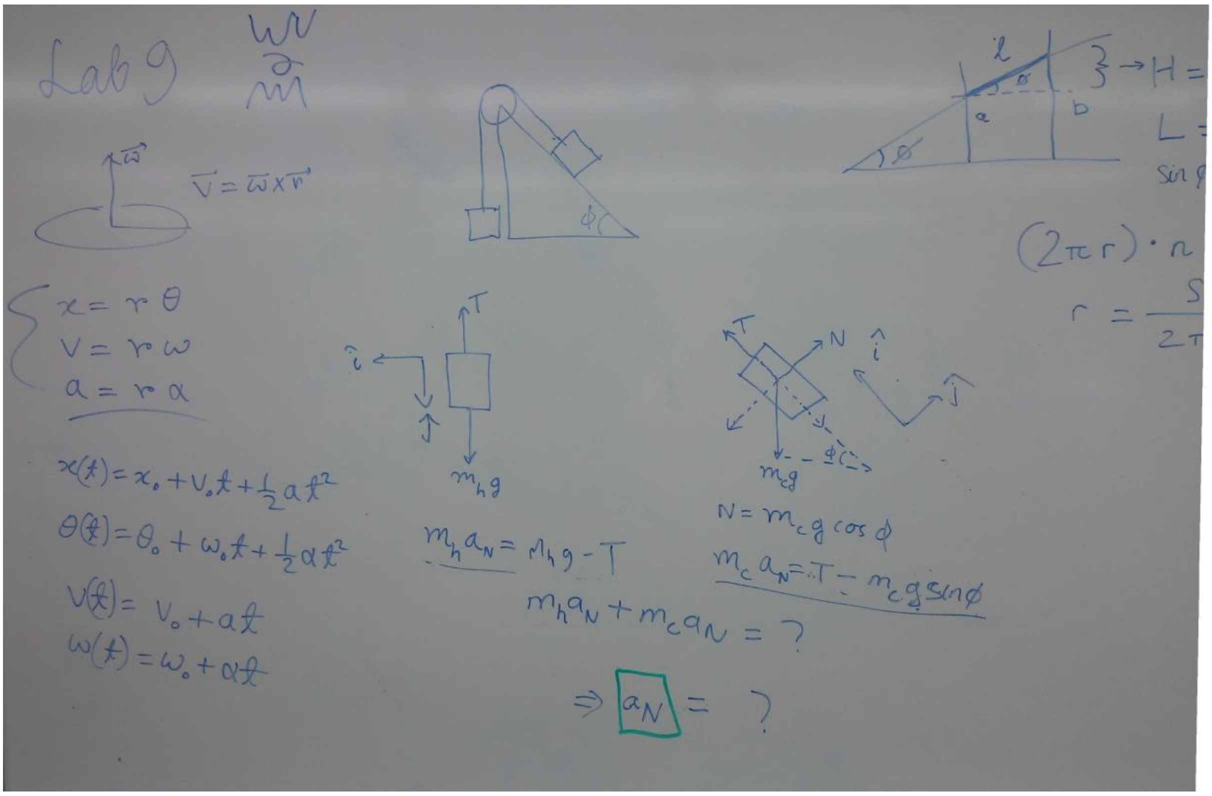
> *"Measure the angle of the track using the meter-stick. It is easiest to measure the height H of the track up from the floor at some convenient point along the track, then the length L of the track down to the floor, and then use your knowledge of geometry to calculate the angle φ of the track up from the horizontal."*

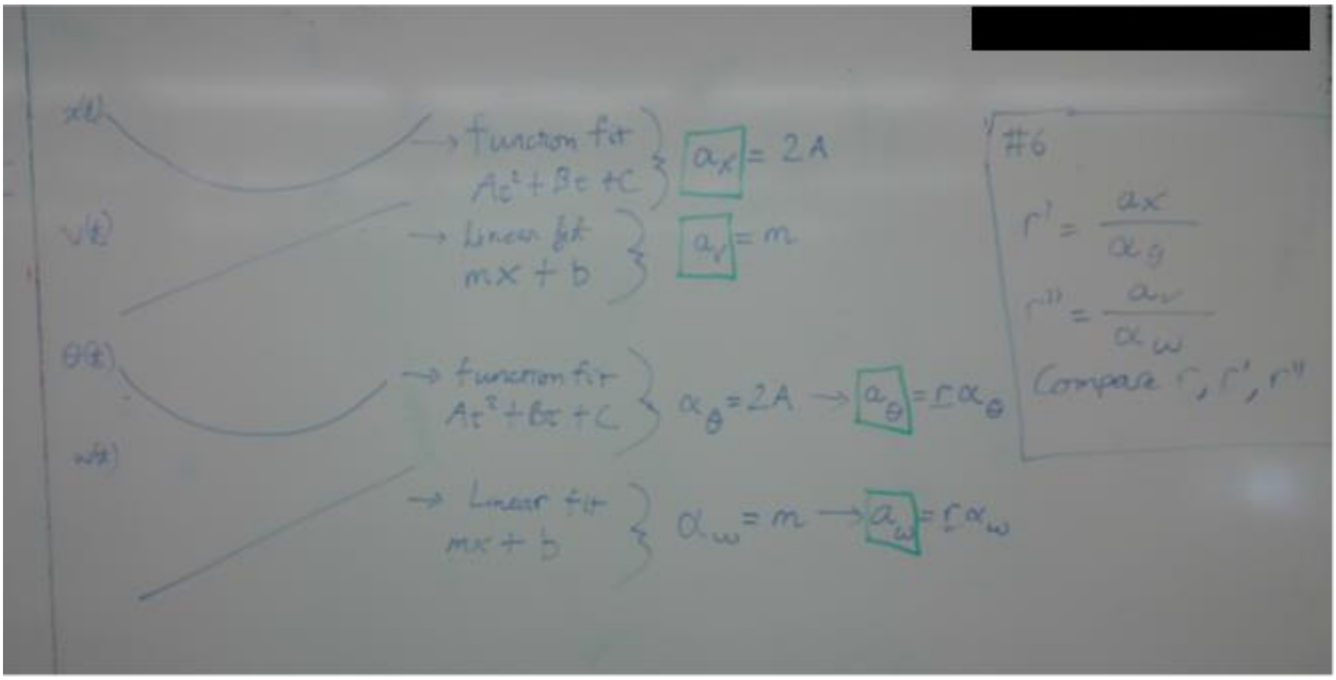
In addition, the directions tell students to put the cart into equilibrium and then add 20g to the hanger. The TA noted that some students in other sections didn't realize that this additional twenty grams should be kept on for the rest of the experiment. There should be a note in the directions to make sure that this is clear to students.

Next, we noticed that one group was pushing the cart with too much force. As a result, the cart was coming very close to bumping into the sensor. It should be further emphasized in the directions that the cart only needs a very light push

Finally, part three of the instructions say, "Note that the "A" in the Logger Pro equation is not divided by 2, whereas the "a" (or "α") in the kinematics expression for x(t) is". The TA noted that some groups thought that this meant that they should be dividing their values by 2. In actuality, it is necessary to multiply by 2.

By forcing students to rely less on the provided instructions, we believe that students will learn much more from this lab. When students are told how to interpret their data, the need to analyze and understand the central concepts is greatly reduced.


Lab 9
$\vec{v} = \vec{\omega} \times \vec{r}$
$x = r\theta$
$v = r\omega$
$a = r\alpha$
$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2$
$\theta(t) = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$
$v(t) = v_0 + at$
$\omega(t) = \omega_0 + \alpha t$
T
$m_h g$
$m_h a_N = m_h g - T$
$N = m_c g \cos\phi$
$m_c a_N = T - m_c g \sin\phi$
$m_h a_N + m_c a_N = ?$
$\Rightarrow \boxed{a_N} = ?$
$(2\pi r) \cdot n$


x(t)
v(t)
θ(t)
ω(t)
function fit
$At^2 + Bt + C$
$\boxed{a_x} = 2A$
Linear fit
$mx + b$
$\boxed{a_v} = m$
$\alpha_\theta = 2A \rightarrow \boxed{a_\theta} = r\alpha_\theta$
$\alpha_\omega = m \rightarrow \boxed{a_\omega} = r\alpha_\omega$
#6
$r' = \frac{a_x}{\alpha_\theta}$
$r'' = \frac{a_v}{\alpha_\omega}$
Compare r, r', r''

PH-1111 Laboratories

1. String and Nuts

Procedure

This experiment actually exposes you to several very different issues:

1. Dimensional analysis. Sometimes, you can find a fair part of the answer to a problem, not all of the answer, simply by knowing that the answer is a time or a length. (In the other direction, if you know that the question asks for a length, and your answer is "two weeks", you should realize that something has gone badly astray.)

2. Improvising equipment. I am supplying you with a string and nuts, but you all get to figure out how to mount the string at the top, fasten things, measure the length and the period, etc. Your write up should say what you did.

3. Experimental design. I am not telling you exactly which measurements to use, for example, that you should or should not use a prime number of different choices of string length, but you are responsible for the quality of your work.

4. Linear least squares analysis. You are going to get measurements for how pendulum period depends on the mass of the nuts, the length of the string, or perhaps the amplitude of the swing. You are expected to determine quantitatively how these variables are related. Linear least squares is an answer.

HOW TO PROCEED:

The period T of a pendulum is how long it takes the pendulum to go through a complete circuit of its path. That could be going back and forth once. It could be the time needed to pass the same point in its swing twice while going the same way. You are here to determine what factors affect the period of a pendulum.

DIMENSIONAL ANALYSIS:

The period T of a pendulum might depend on several other variables, such as the length L of the string, the mass m of the nuts, and the gravitational constant g. However, T has the dimensions of a time and therefore when you combine L, m, and g, the combination

$L^x\ m^y\ g^z$ Equation 1

must have units 'time', so that

$T = K\ L^x\ m^y\ g^z$, Equation 2

where K is a simple, unitless number, e.g., 42.3142.

GETTING THE EXPERIMENT TO WORK:

There are at least three interesting questions in measuring the period.

1. Should you measure from maximum to maximum, or should you time zero crossings? For some combination a mass and string length, measure the period ten times using each

method. Find the average period...are the two average periods more-or-less equal? What is the scatter in your measurements using each method?

2. How do you avoid parallax and sighting errors? This question is more important for timing zero crossings. A single sighting point behind the area where the pendulum is swinging does not work, because your head tends to move from side to side. One reliable method to get an accurate measure is to sight along two points, keeping the two points lined up. (Those of you who have learned how to aim a rifle or pistol will find this very familiar.) When the string crosses your line of sight, you have a very well-defined moment in time. As an alternative to line of sight, some of your classmates may have a laser pointer that gives a sharp line; wait for the pendulum string to intersect the laser beam.
3. Random timing errors. You have a hand and a stopwatch. The error in the timing, based for example on careful studies of timing athletic events, is about 0.1 second if you are lucky. You have the same error at the start and finish. One way to improve timing accuracy is to time some large number of swings, say 5 or 10. Your timing error stays the same, but the error per swing falls inversely with the number of swings.

Before doing anything else, you should construct one pendulum and confirm that you are getting reproducible results for the pendulum's period T. If you are not, you should fix this problem before you do the actual experiment.

DOING THE EXPERIMENT

1. Do the dimensional analysis, for equation 2, find and report the powers a, b, and c, and explain how you found them.

2. Get your pendulum to work. See the prior section. Your report should explain how you dealt with the issues I raise.

3. Do the needed measurements.

HINT! Take a few measurements. Graph them. Do a least-mean-squares fit, and plot the line you found. See if your approach is working AT ALL before you waste a lot of time taking bad measurements. (Also, by doing the analysis you will check if you measured all the numbers you needed. For example, if you record the time for a number of swings, and forgot to write down *how many* swings there were, your data is totally worthless because something is missing.) If the analysis appears to be working, take a larger set of measurements. This hint is probably the most important thing to carry away from this lab. People who say they will take all the data and then do the analysis later are dangerous, and you should avoid them when MQP time approaches.

The simple approach is to measure the period of the pendulum for a series of different values for L and m. While changing each variable, hold the other variable constant. However, if varying L, use at least two different values for m, and vice versa.

If you think T also depends on some other variable, then measurements with fixed L and m will sometimes give different values for T. Did you observe this effect? Hint: See if the period stays the same when you make the size of the swing larger or smaller by using different starting points.
4) Analyze your data to determine your experimental values for a and b.

ANALYZING THE DATA: LEAST-MEAN-SQUARES FITTING

Eventually, you will have a set of measurements that give you T for different values of L or m. You

should plot these points and see if any of the points look really strange, for example because you recorded 1.5 seconds as 15 seconds.
If you have a "power-law" relationship between the variables x and y

$y = a\,x^b$ Equation 3

then by taking the logarithm you have

$\log y = \log a + b \log x.$ Equation 4

Observe that log(y) is linear in the variable log(x). The x and y here are not the same as the exponents x and y in equations 1 and 2. Apply to equation 2 the steps leading from equation 3 to equation 4. You will get an equation in log(T) that can be combined with least mean squares fitting to determine a and b of equation 4 (K, x, y, of equation 2).

You WILL use linear least squares and this result to determine from your measurements the constant K and the exponents x and y of equation 2. The instructions for doing least mean squares are found below. You will do your least mean squares calculation by hand (you may use a calculator to do your arithmetic operations).
Least Squares Fit

Our Analysis

Since this is the first lab, an introduction is necessary. The TA began the class by demonstrating how to navigate the MyWPI site. After the demonstration, the TA passes out the FCI exam, and the students fill it out. We think that this demonstration is important, it clears up any confusion that first year students have.

Then, the TA read through the experiment instructions, which is a take home. The students are given string and nuts to create a pendulum anywhere on the campus. Students record the period of the pendulum (T) for different lengths of string (l) and different masses (m). Then the students graph their data length against period, and mass against period. Using the graphed data the students create a least-mean-squares fit line and determine the two coefficients (a and b) of the power law equation, $y=ax^b$.

This experiment is a good introduction, but while we have the students in the laboratory shouldn't they just do the experiment there? We're not sure why the first laboratory is a take home experiment; it's also the only experiment that students are required to complete at home. We think it would be better for the students to work together in the laboratory. Since time in the laboratory is scarce, no time should be wasted. The students left after the materials were handed out which only took about a half hour. The students are not forced to leave the laboratory but the TA gives them the option to leave -- an option that every student took. Alternatively, the rest of the laboratory time could be used as a Logger Pro introduction since students always have trouble with the software at first. We would suggest that the second half of the available hour be put toward something productive.

The laboratory instructions expose the students to four important skills; dimensional analysis, improvising equipment, experimental design, and linear least squares analysis. The TA's go over the laboratory instructions with the students by explaining each section in better detail and answering questions the students have along the way. The dimensional analysis section doesn't have too much detail. It identifies the variables on which the period is dependent on and sets up a basic equation based on those variables, $T = K\ L^x\ m^y\ g^z$, where K is a dimensionless constant. This section of the instructions does a good job teaching the students how to set up a basic equation by analyzing the variables that a value is dependent on.

Improvising equipment and experimental design go hand in hand. Students are given a length of string and nuts and told to measure the period of a pendulum for various lengths of string. To do so, they have to improvise with the equipment given, in this case creating a simple pendulum. The experimental design skill ties in with designing the pendulum. Students have to design a functioning pendulum and figure out the best way to record the period while minimizing error.

The last section of the instructions focuses on analyzing the data using a least-mean-squares fit. The instructions first manipulate the power law equation so that it is linear, log(y)= log(a)+ b log(x). Students are given a link that sends the students to a page explaining how to do a least squares fit by hand. The students graph the data they gathered, as a log-log plot, and then perform a linear least-mean-squares fit by hand to get values for unknown coefficients and end with an equation for period. The instructions were very informative but also easy to follow, perfect for a first lab. The instructions also do a good job explaining dimensional analysis, improvising equipment, experimental design, and linear least squares analysis. These are useful laboratory skills for the students to use in future labs.

2. Force Diagrams for Single and Double Pendula

Procedure

PH-1111 - Force diagrams for Single and Double Pendula

Purpose: To demonstrate creating force diagrams for various physical experiments. In particular we want you to create force diagrams for the single pendulum and the double pendulum. As part of this exercise we will also want you to compare a theoretical calculation with actual measurements.

Equipment: We provide you with a number of hanging devices, measuring tools, string as well as the string you have used for the simple pendulum take home exercise, weights and so forth. You are asked to provide the ingenuity.

A double pendulum, with forces being measured: Consider Figure 1. In the figure, the shaded area at the top is a support, m_1 and m_2 are the two masses of a double pendulum, and the lines linking the top support, $m_{1,}$ and m_2, are strings. The lengths of the strings are L_1 and L_2 as marked on the figure. The dashed lines represent the vertical, the two angles being the angles between each string and the vertical.

The objective of the experiment is to set up the double pendulum (you'll also do a single pendulum), put known sideways forces on each mass, set up the force diagram for each mass, and compare the measured deflection (sideways displacement) of each mass with the deflection that you calculate. You are not set up to measure the tension in each string, but when you the two measurements the masses are just sitting there. Their accelerations are zero, so the total force on each mass is zero.

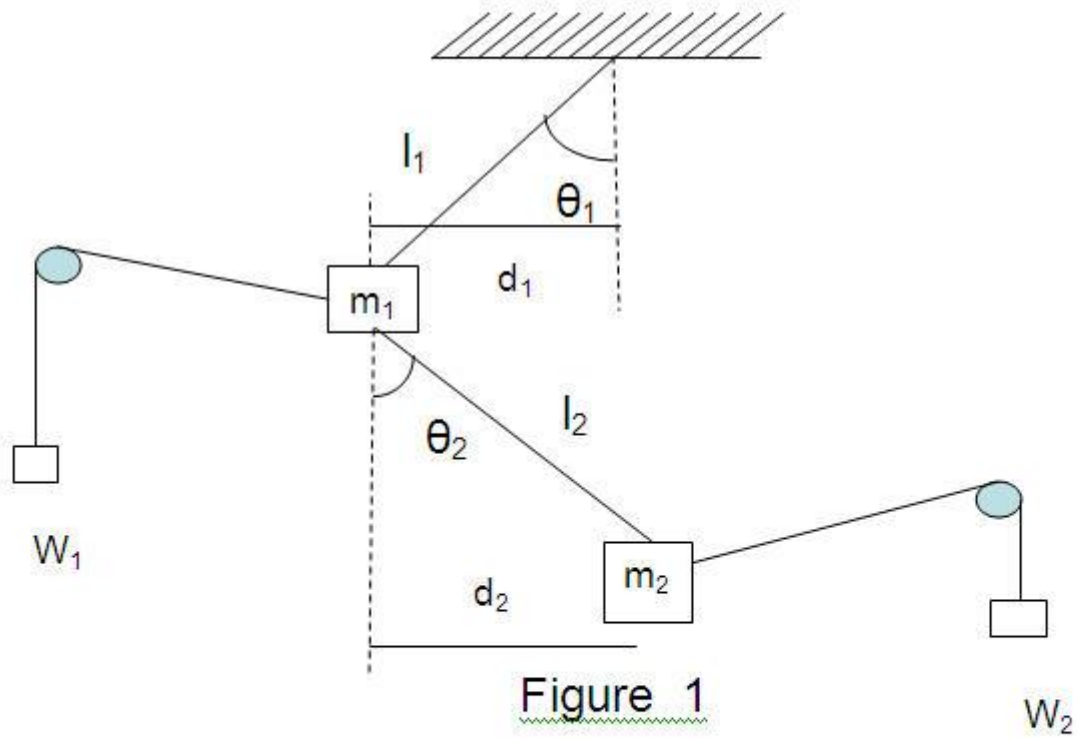


Figure 1

To simplify the grader's task, the lengths of l_1 and l_2 should both be 0.7 m. The two masses should also be the same, about 0.2 kg.

To measure the deflections, you have two choices. One is to mount a protractor whose vertical axis can be determined ("by eye" does not work), and line up the origin of the protractor with the correct point on the string. The second is to create a vertical reference axes using clamps and rods, align the vertical carefully with the line occupied by the two masses when no sidewise forces are being applied, and measure the *horizontal* deflection of each mass. Note that when the masses move sideways, they also move up and down, so the horizontal deflection is not the distance from the starting point to the ending point.

Having found an accurate way to measure the deflections, which may not be entirely easy, use masses W1 and W2 and strings and pulleys as indicated to apply transverse forces to m1 and m2.n You will need to move the pulleys until the forces applied by W1 and W2 are horizontal.

What to do in the Lab:

In the lab you will measure both for a single pendulum (one string, one mass) and for a double pendulum (two strings, two masses, one mass hanging from the other mass).

1) For the simple pendulum you will use three different values for W1. For each W1, you will measure the displacement. You will measure the angles as discussed above. Construct nice tables to keep you work organized and easy to follow. Calculate the tension in the string. Calculate the deflection, and compare with your measurements. Provide three complete force diagrams including all appropriate forces, angles and displacements.

2) For the double pendulum there are four obvious experiments: A) using W1 and not W2, B) using W2 and not W1, C) having W1 and W2 on the same side of m1 and m2 and, finally, D) having W1 and W2 on opposite sides of m1 and m2. Again you will need a table, several

diagrams, and the measured and calculated displacements.

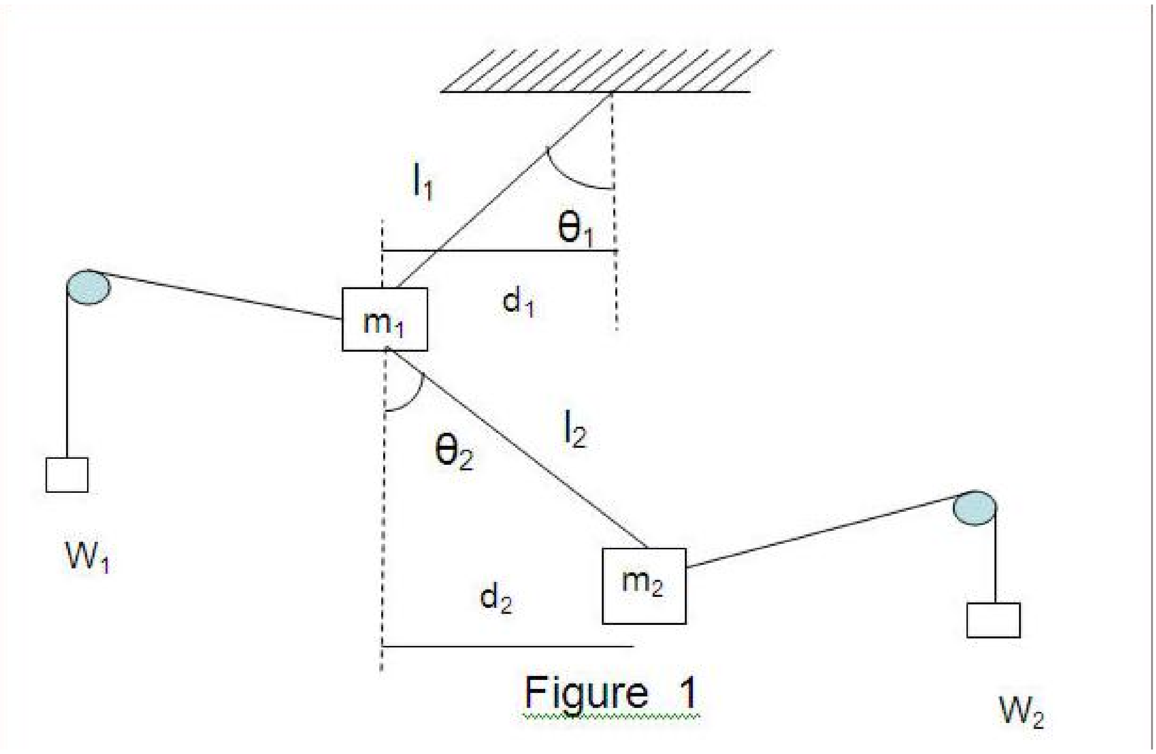
DISCUSSION

This is a static experiment. The accelerations of m1, m2, W1, and W2 are all zero. Therefore the total force on each mass must also be zero. However, we cannot measure the tension in either string. Therefore, we use the second law (and acceleration equals zero) to compute the tensions from the known forces and angles. However, from m1, m2, W1, W2, L1, L2, and the horizontal direction of the forces due to W1 and W2, you can also calculate what the two angles theta should be. Compare your calculated values with experiment.

Our Analysis of this Laboratory

In the single and double pendulum lab, students are given some string and a few different masses and are asked to create a simple pendulum hanging one of the masses. The students measure the angle created before releasing the pendulum (Θ), the lateral displacement of the pendulum (d), and the tension of the string (T). Then they change the mass and take the same measurements, repeating this process for a total of three trials. After each trial the students draw a force diagram of that pendulum to calculate the tension in the string. After all three trials have been completed the students organize their data into a chart and compare their experimental data to theoretical calculation.

The second part of this experiment requires the students to create a double pendulum system, shown below is a diagram of the system from the laboratory instructions.



The values for l_1, l_2, m_1, and m_2 are given. Students use different masses for W_1 and W_2 and measure the different deflections, d_1 and d_2, and the angles, Θ_1 and Θ_2.

There were a few noticeable issues with this lab, the first being that it was too long. This laboratory is split into two, fifty-minute sections. The second section is unnecessary, only three groups of about 12 total needed the section to finish the experiment and those groups did not need more than 30 minutes of the second section. We would suggest omitting the second section of this laboratory and instead giving students a single, 50 minute section to conduct the experiment. Since most groups did not need the second session, we think that the time can be put toward another laboratory that needs a second session more. For instance, we think that students would benefit from having more time to complete PH-1111's Conservation of Energy experiment. Part one of this experiment, the simple pendulum, is very similar to the take home lab. Since the students create the same pendulum we would suggest omitting this experiment from the lab as well because the second part of the lab demonstrates force diagrams well enough on its own. The instructions do not present the goals of this experiment well enough. The instructions also could have included a diagram of the simple pendulum since there was a diagram of the double pendulum. Aside from those suggestions the lab ran smoothly. The students created the pendulums without any significant problems and their experimental data was close to their theoretical data.

3. Cart on a Steep Slope

Procedure

Overview

Goals: To explore the relationship between friction, acceleration and track angle.

Objectives: This laboratory has two experimental parts and one analytical part. In the first part of the experiment, you will choose a weight such that it and the cart are in static equilibrium, and then after a small push, you will measure the up, down, and average accelerations of the cart. In the second part, you will add ten grams of mass to the weight and measure the accelerations again. The analytical part consists of calculating, from your measurements, the angle of the track and the friction acting on the system.

Purpose: The purpose of this experiment is to give you experience in analyzing the motion of two objects connected together so that their motions are linked. Even though these two objects travel in different directions – the magnitudes of their displacements are identical on a moment-by-moment basis, as are the magnitudes of their respective velocities and the magnitudes of their respective accelerations. In this particular case, one object will be the Vernier cart (whose state of motion is monitored by the motion sensor) on the steeply-sloped 2-m track and the other is a freely hanging weight.

Part 1:

Procedure: Your experimental apparatus will be set up as follows: the 2-m track will be mounted at a steep angle with the horizontal and the motion detector will be placed at the lower end of the track. The cart will be attached to a mass hanger by a strong, light-weight string that passes over a pulley at the top end of the track. The string will be long enough so that the cart can traverse most of the track length while the mass hanger moves through a vertical range from near the pulley to near the floor. In this first part of the experiment, the amount of mass on the hanger will be adjusted (to the nearest gram) so that the cart and mass hanger will remain stationary wherever they are placed.

If you find your cart/hanger arrangement NOT mounted on the track, first measure the mass of the cart and then of the empty hanger on one of the mass balances available in the lab. If you find your cart/hanger arrangement in place on the track, OR if you have finished measuring the cart and hanger masses, then go to the next step. Be sure to measure these masses at a convinient[sic] pause in data acquisition. Keep in mind the limited number of scales in considering whether or not to pause.

With the cart on the track and the mass hanger hanging straight down from the pulley, add mass to the hanger until an equilibrium is reached where the cart/hanger system will remain stationary in equilibrium wherever it is placed. This will require adjusting that hanging mass to the nearest gram. You can also check your equilibrium by giving the cart a slight push up the incline, then down the incline. When you have reached the best equilibrium, the cart will coast roughly the same distance from the same tiny push no matter its direction of motion, up or down the track. When you have obtained a good equilibrium condition, record the mass-value of the slotted-masses-plus-mass-hanger on a sheet of scratch paper (including the mass of the hanger, which is close to 0.050 kg).

Once you have finished adjusting the hanging mass for the equilibrium condition, make a recording of the cart's x vs. t motion DOWN the track along with the attendant v_x vs. t graph as presented by the Logger Pro template for this part. As you did in when studying Acceleration of a Cart, determine the acceleration of this motion, complete with uncertainty, by performing a least-squares fit to the v_x vs. t graph and record the value for later use. Label this acceleration a_{down1}. Repeat for the cart coasting UP the track. Label this acceleration a_{up1}.

Use the meter stick to determine the angle of the track.

Part 2:

Procedure: Once finished with the equilibrium experiments of Part 1, you should proceed with the following.

Place an additional ten-gram mass on the mass hanger, thus putting the system in a non-equilibrium situation (which will require you to hold the cart or mass hanger to keep the system from getting away from you between runs). Holding on to the cart lightly, move the cart to the high end of the track, but not so high that the mass hanger strikes the ground. Practice giving the cart a push down the incline so that it coasts more than half the track length down toward the motion sensor and back. Important: As the cart nears the pulley-end of its travel, reach up and gently stop the cart before it crashes into the pulley. Likewise, please prevent the cart from crashing into the motion sensor.

Once you have developed the right push-touch, start the motion sensor recording using the Logger Pro template for this part. If your first recording is not the best, repeat the recording process until you obtain a good one. At this point, you can remove the extra 10-g mass to restore equilibrium so that the system will remain motionless while you analyze these latest data.

Determine three acceleration values by least-squares fitting a straight line to the v_x vs. t graph: the acceleration value when the cart was moving DOWN the incline, the acceleration value when the cart was moving UP the incline, and the average acceleration of the total of DOWN/UP motion (recall that in this last case you select a range that includes approximately equal portions of the UP and of the DOWN motions). Label these values a_{down2}, a_{up2}, and a_{ave2}, respectively.

Once you obtain values for these three accelerations, each complete with its uncertainty, and have recorded everything on scratch paper, you are finished with the data acquisition. If you have not yet measured the mass of the cart, you should now CAREFULLY disconnect the string from the mass hanger, unthread the cart-plus-string from the pulley, and then measure the mass of the cart to the nearest gram on one of the mass balances located around the room. You should also double-check the hanging-mass values (with and without the ten grams) by putting the whole hanger-plus-slotted-masses on the balance, and comparing your measurement with the prediction of the numerical sum of the numbers stamped on the several masses.

Worksheet

WPI **Physics**

PH 1110 - Cart on a Steep Slope - Worksheet

Name & Section: **Partner's Name & Section:**

1. In the frame below this problem statement, write down your raw data from Part 1. Report the masses as determined by the mass balance to the nearest tenth of a gram. Your raw acceleration values, of course, need to be reported in the form "ave ± sd," with units.

$\mathbf{m_{hanger1}}$ =	$\mathbf{a_{down1}}$ =
$\mathbf{m_{cart}}$ =	$\mathbf{a_{up1}}$ =

2. Find the angle of the track. Show your work, and report angles to the hundredth of a degree.

$\boldsymbol{\theta_1} = \mathbf{arcsin(m_{hanger1}/m_{cart})} =$

3. Calculate the magnitude of the friction $F_{friction1}$ based on the accelerations a_{down1} and a_{up1}. Show your work, and report your friction values to three significant figures.

$\mathbf{F_{friction1} = (1/2)\,(m_{cart} + m_{hanger1})\,(a_{down1} - a_{up1})}$ = =

4. In a few sentences, explain how you determined the angle of the track from trigonometry and show your calculation.

 $\boldsymbol{\theta_2} =$

5. Report your raw data from Part 2, as in Exercise #1.

$\mathbf{m_{hanger2}}$ =	$\mathbf{a_{down2}}$ =
$\mathbf{m_{cart}}$ =	$\mathbf{a_{up2}}$ =
	$\mathbf{a_{ave2}}$ =

6. Calculate the angle of the track from the masses and accelerations. Show your work. Use g = 9.801 m/s^2.

θ_3 = arcsin[($m_{hanger2}$/m_{cart}) – (a_{ave2}/g)(1+($m_{hanger2}$/m_{cart}))]
=
=

7. The angle values determined in Exercises #2, 4, and 6 should be the same to within a degree, in which case you should average them together to obtain a good value for the track angle. If the angle values are different by more than a degree, please call your lab instructor over to have a look at your calculations. One way or another, the problem should be found and fixed, or all of your work will be in doubt. Report your average here.

θ_{ave} =

8. Calculate the standard deviation of the angles, using the formula

$$sd = \sqrt{\frac{\sum(\theta_i - \theta_{avg})^2}{(N-1)}},$$

where i is the index of the value (here, it runs from 1 to 3) and N is the total number of measurements (here, 3). The "∑" sign means that you add all the squares of the differences between the three values and the average. Now report the angle in our form, "ave ± sd," with units.

sd = Sqrt{[∑(θ_i-θ_{ave})^2]/(N-1)} =
θ =

9. Calculate the magnitude of the friction $F_{friction2}$ based on the accelerations a_{down2} and a_{up2}. Show your work.

$F_{friction2}$ = (1/2) (m_{cart} + $m_{hanger2}$) (a_{down2} – a_{up2})
=
=

10. As in Exercises #7 and 8, find your average friction and its standard deviation, then write them in proper form.

F_{ave} =
sd = Sqrt{[∑(F_i-F_{ave})^2]/(N-1)} =
F =

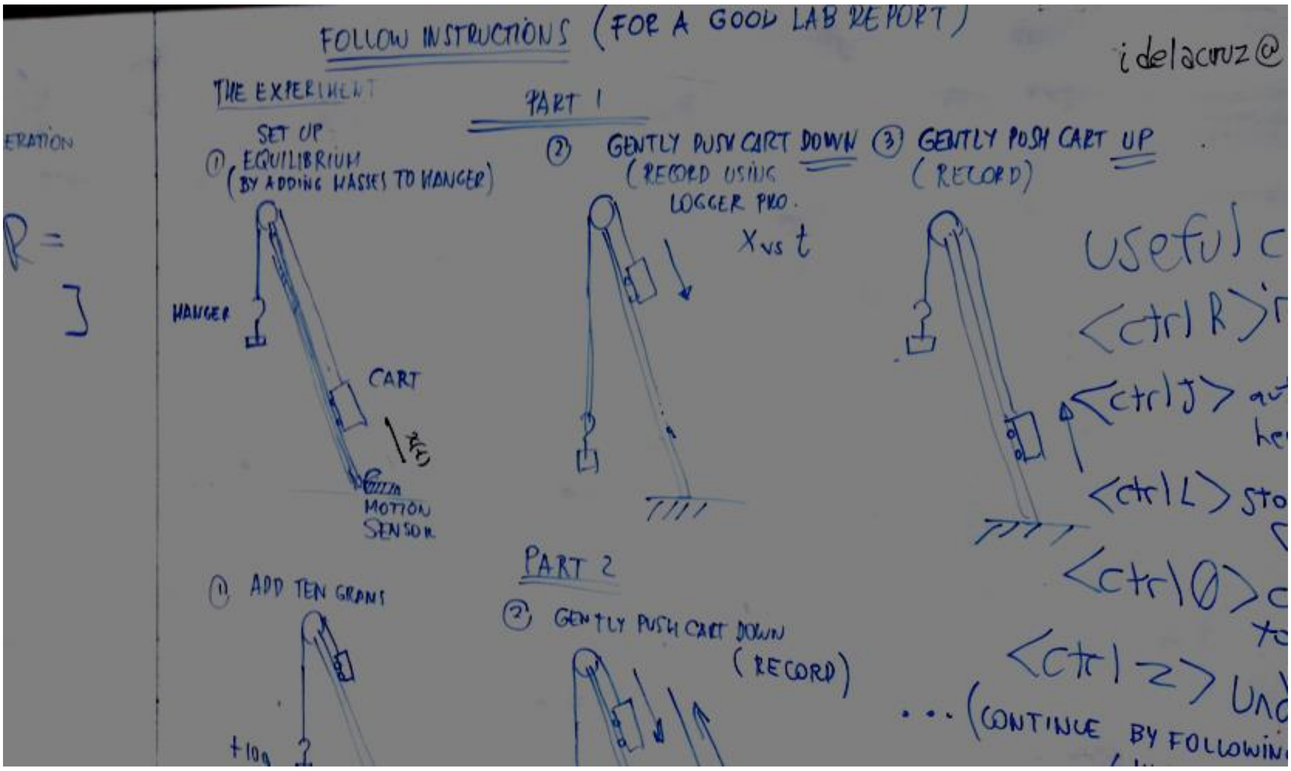
11. Should your friction values be the same? Is the standard deviation a few percent of the average value? Is your experiment successful? Answer in one or two complete sentences.

Our Analysis of this Laboratory

This lab is called "Cart and Hangar Acceleration" because it contains an experiment that features a cart on a sloped track being pulled by an attached hanging mass or a “hanger”. The experiment is set up with the cart on the slope with the hangar attached to the cart and run up the length of the track. The mass is then looped over the track, using a pulley, so that it is hanging freely. A motion sensor is placed at the bottom of the track to collect data using Logger Pro. In the first part of the experiment the students choose a mass that holds the cart motionless at equilibrium on the track. Once the cart hangar system is at equilibrium the students nudge the cart down the track and record a velocity vs. time graph using Logger Pro. The students then perform a least-squares fit to the graph to get a value for the acceleration down the track. After this experiment is complete the students use a meter stick to find the angle of the track.

In part 2 of this experiment the students add 10 g to the equilibrium mass from part 1. The students then set the cart at the top of the track and push it down the track so that the hangar pulls it back to the top. The motion sensor collects data again in a velocity vs. time graph. The students perform another least-squares fit to this graph to find a downward acceleration and an upward acceleration. This labs function is to teach students the relationship between friction, acceleration, and angle. The experiment does a great job of exploring that relationship. We wouldn’t change the procedure at all. There are a few minor bugs in this lab mainly in the set up of the experiment. One group of students did not use a pulley, another group had to ask how to push the cart down the track, one group pushed the cart too hard and it smashed into the motion sensor. It seemed clear that the students were confused about the procedure. We suggest a TA demonstration at the beginning of the lab along with the usual introduction that the TA’s give. During the introduction the TA’s drew diagram for each part of the experiment. We think it would be more helpful if these diagrams were included in the instructions. The students struggled with Logger Pro again, mainly with the least-squares fit function. Lab 1 has the students calculate the least-squares fit by hand so many students thought this part of the lab could be done at home. Other issues with Logger Pro were mainly problems navigating the software. We suggest some training in using Logger Pro for the students.

After one lab section Alec and I caught up with the two TA's to ask for their thoughts on the first few labs of the term. The TA's told us that they also find Logger Pro difficult, they have no training in using the software either. Having the students confused with the software is one thing, but when the TA's do not offer enough assistance that is a serious problem. One TA expressed that there is a disconnection between the lab TA's and the professors. The TA said that he/she had only talked to the professor of his/her section once before the term had started, and then never heard from him again. The TA also suggested a weekly or biweekly meeting between the TA's and the professors to



reinforce what is being taught in the class and how it pertains to the labs. The TA's also told us that they see a large variation in the amount of effort that each group puts into the lab. They also said that there is no specific grading rubric so it can be difficult to grade the labs. The TA's suggested a clearer grading rubric with a more specific guideline for grading the labs. Based on what we heard from the TA's, they feel that the labs are disorganized. They found it difficult to clear up what they found confusing. The TA's are not given a formal training in the labs. If they don't meet enough with the professors or lab supervisor then they can get overwhelmed. That disconnection must be addressed.

Scheduling meetings would help to solve that problem, but we think a formal training with the professors and lab supervisors would suffice.

4. Work-Energy and Momentum

Procedure

Overview

Today you are going to record the speeds of two carts before and after a collision. You will do this twice, once with one cart with a nearly elastic plunger extended towards the other cart, and once with shock-absorbing material placed at the points where they hit each other. You will calculate the carts' kinetic energies and momenta and observe how they change.

There are three parts to this experiment. Part I concerns theory, Part II, data collection, and Part III, analysis. Ideally, you have tried Part I before arriving in lab so that you will have plenty of time to complete the worksheet. If not, start with Part II. Collect the data for Question 3 and the yellow boxes of Question 4, then return to Part I.

Part I, Theory

- In your notebook or on a piece of scratch paper, sketch free-body diagrams of a cart traveling at constant velocity on a horizontal track, a cart at rest on a horizontal track, and the two carts when they collide. Label the forces. Friction is negligible.
- Write out the work-energy theorem and the principle of conservation of momentum in

words and equations.

When you are satisfied, open the worksheet and answer Questions 1 and 2. Check with your lab instructor to confirm that your free-body diagrams, statements, and equations are correct. Then move on to Part II.

Part II, Data Collection

• You will use two carts and two motion detectors today. Place a motion detector at each end of the track facing the middle of the track. One cart should have a plunger; they each should have two Velcro tabs on one bumper. One cart should have one or two masses attached. The cart without the mass(es) attached should be on the left (Cart A). The track should be level, such that when you place the carts on the track at rest, they stay at rest. It doesn't matter if you start with the plunger extended or retracted. The plunger (or Velcro tabs) should face the other cart. Open today's Logger Pro file.

• When a mass balance is free, determine the masses of your carts. Record the masses in the yellow boxes of the tables, with the units in square brackets. For the more massive cart, you will have to hang additional mass on the balance in order to obtain an accurate value. Next to "Collision:" on the tables of the worksheet, type a short description of which collision the table will be, e.g. "with plunger" or "with Velcro."

• With Cart A (without masses) at about 20 cm in front of the left-hand sensor and Cart B (with masses) in the center of the track, gently give Cart A a momentary push while acquiring velocity data. Please prevent Cart B from crashing into the right-hand motion detector.

• You shall see sudden changes in the v(t) traces that represent the change in velocities during the collision. Measure the x-components of the velocities of Carts A and B just before and just after the collision. Use the statistics function ("STAT") on the upper toolbar, setting the brackets around ten to fifteen datum points. Record the mean values of the x-components of the velocities in the yellow boxes of the table, where, for example, v_{Ai} is the initial x-velocity of Cart A and v_{Bf} is the final x-velocity of Cart B. Indicate the direction of motion with the convention that motion to the right is positive. Paste your graph into the appropriate box on the worksheet such that its width is roughly half the width of the box and the data and data boxes are readable.

• If your first data acquisition was with the plunger extended, depress it now, and vice-versa if your first run was with the plunger retracted, such that the Velcro kept the carts together after the collision. Directly above the plunger is a release pin for extension and an oval catch to hold down as you push the plunger in.

• Repeat the data collection, and then move on to Part III, Analysis.

Part III, Analysis

• At this point, all the yellow boxes in the tables of the worksheet should be full. Now is a good time to put all of the units of your data into the square brackets.

•In the following, remember that to calculate a change, you subtract the initial value from the final value, e.g., $\Delta K = K_f - K_i$. Lower-case variables refer to an individual cart and upper-case ones to both carts.

• Calculate the kinetic energies of the individual carts before and after the collision and place your values into the green boxes in the second column. At the top of the third column, calculate the change in kinetic energy of the individual carts. Then calculate the initial and final kinetic energies of the two carts summed together, followed by the change in kinetic energy of the two carts, and finally divide the change in kinetic energy by the initial kinetic energy (the proportional change in kinetic energy).

• The fourth and fifth columns for the momentum follow the same pattern as the second and third columns for kinetic energy. The fourth column contains the x-components of the momenta for the individual carts just before and just after the collision. The fifth column is for the values of the momentum changes for the individual carts, the total initial and final momenta, the change in total momentum, and the change divided by the initial momentum.

- There are four fractional changes on your worksheet. Two should be greater than 0.100, and two should be less. Make sure you understand why before you answer the individual questions on the worksheet.

If all has gone well today, you will have demonstrated that independent of the materials involved one entity (kinetic energy or momentum) is conserved (i.e. remains the same) during a collision, and the other one is not. The other entity will be very different depending on the kind of collision.

Worksheet

Work-Energy and Momentum

Name and section number:
Partner's name and section number:

1. Sketch free-body diagrams of a frictionless cart moving at constant velocity, a cart at rest, and two carts colliding. Label the forces. You may enlarge the drawing canvas and move captions.

A cart at constant velocity, a cart at rest

The two carts colliding

2. Write the work-energy theorem and conservation of momentum in words and equations.

3. Paste your two graphs into the box below, with data and data boxes legible.

a)

b)

4. Enter your raw data into the yellow boxes and your calculated data in the green boxes. Enter the units in the square brackets. All data in the table should have at least four significant figures.

m_A=	[]	m_B=	[]	Collision:					
x-Velocity []		Kinetic energy []				x-Momentum []			
v_{Ai} =		k_{Ai} =		Δk_A =		p_{Ai} =		Δp_A =	
v_{Af} =		k_{Af} =		Δk_B =		p_{Af} =		Δp_B =	
v_{Bi} =		k_{Bi} =		K_i =		p_{Bi} =		P_i =	
v_{Bf} =		k_{Bf} =		K_f =		p_{Bf} =		P_f =	
				ΔK =				ΔP =	
				$\Delta K/K_i$ =				$\Delta P/P_i$ =	

m_A=	[]	m_B=	[]	Collision:					
x-Velocity []		Kinetic energy []				x-Momentum []			
v_{Ai} =		k_{Ai} =		Δk_A =		p_{Ai} =		Δp_A =	
v_{Af} =		k_{Af} =		Δk_B =		p_{Af} =		Δp_B =	
v_{Bi} =		k_{Bi} =		K_i =		p_{Bi} =		P_i =	

v_{Bf} =		k_{Bf} =		K_f =		p_{Bf} =		P_f =	
				ΔK =				ΔP =	
				$\Delta K/K_i$ =				$\Delta P/P_i$ =	

5. *In your own words,* state which data pair in the tables should be equal and opposite. Is your statement consistent with your free-body diagrams of the collision? Should it be?

6. *In your own words*, discuss why the $\Delta K/K_i$ values are very different for the two experiments, yet the $\Delta P/P_i$ values remain approximately the same. Where does the “lost” energy go? How does work get done on the carts?

Our Analysis of this Laboratory

This is a collisions lab that has two sessions. In part 1, of this lab, the students observe the momentum in a collision between two carts on an isolated track. Part 2 deals with the same collision but the students observe the energy in the system instead of the momentum. The experiment is simple, the students set up two carts on a track along with a motion sensor to measure velocity. First the students measure the mass of the carts. Then they use the motion sensor to record velocity values of a cart in elastic then an inelastic collision. Then the students observe the graph created by Logger Pro and answer questions on a worksheet.

The organization of this lab could use a little work. As mentioned before it requires two sessions, but there is a different lab between the two sessions. The lab sessions are currently set up in this order; lab 4 part 1, then lab 5, and then lab 4 part 2. The students were confused as to why lab 4 was set up with lab 5 between its 2 parts. Questions from the students, mainly about lab submission, piled up and slowed down the lab. We think there is really no reason to create confusion with how lab 4 is set up. Although the experiment is similar the second part of this lab could just be called “lab 6” instead of lab 4 part 2. Or lab 5, which is also a conservation of energy lab, could be moved to after lab 4 part 2. The current lab organization is creating unnecessary confusion something should change since it is such an easy fix.

Physics Professors have told us that the lab4 is set up with lab 5 between it to go along with the material being covered in the course. However, the TAs are unaware of why lab 5 is between both parts of lab 4. The TAs and the Professors should be on the same page when it comes to lab organization. The TAs should be aware of the topics that the course is covering at the time of each lab section. For example, the TAs should know that part 1 and part 2 of this lab are separated because momentum is taught in lecture before energy conservation. However we heard TAs tell students they had “no idea” why lab 4 is organized the way it is. How can the TAs help the students understand the concepts better if they don’t know what the students have been introduced to in the class? TAs need to be up to date on what is being covered in class lectures to better help the students. A closer relationship between the TAs and the Professors would help fix that problem.

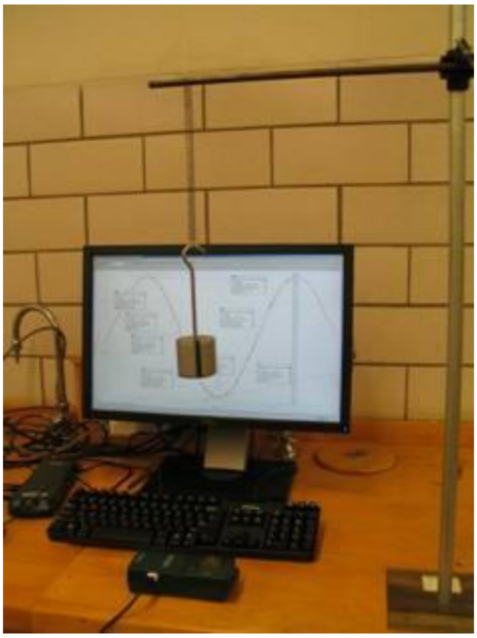
The TAs told us that they think this lab is too focused on “data crunching”. They think that this lab is not engaging the students because are spending too much time reading a graph and typing values into a data sheet. The worksheet contains a large data sheet where students type in values that they read off a graph or calculate. There are 2 conceptual questions where students are asked to describe the experiment “in your own words”. The experiment is quick so most of the student’s time is spent looking at a graph in Logger Pro, which isn’t very engaging. This lab could do a better job engaging the student’s interest, especially with a topic like collisions. We suggest focusing this lab on the experiment more than the numbers.

5. Conservation of Energy

Procedure
Overview

You have likely heard that "energy is conserved." This lab explores whether or not that is actually true. You will set a mass on the end of a spring into oscillation and determine its gravitational and spring potential energies, as well as its kinetic energy, at various positions in its oscillation to see if the energies add up to the same total. The sum of the kinetic and potential energies is called the mechanical energy.

There are two parts to this experiment. Part I concerns theory and Part II, the experiment. Ideally, you have tried Part I before arriving in lab so that you will have plenty of time to complete the worksheet. If not, start with Part II. Collect the data for Questions 4-6 on the worksheet, then return to Part I.



Part I, Theory

- Make free-body diagrams of a mass oscillating up and down on the end of a spring for three situations: equilibrium, accelerating up, and accelerating down. Label the forces using mg and ky, the magnitude of the spring force. Also indicate if the situation corresponds to the top, middle, or bottom of the oscillation.

- If the zero of the potentials is the unstretched position of the spring, write out the gravitational and spring potentials, as well as the kinetic energy, for the top, middle, and bottom, of the oscillation. Use the variables m (mass), g (magnitude of gravitational acceleration), y_t, y_m, y_b (y-positions), v_m (speed at middle), and k (spring constant), where the subscripts refer to top, middle, and bottom. The positive direction of the coordinate system that we are using is up.
- Write the total mechanical energy (kinetic plus potentials) for each of the three situations: top, middle, and bottom.

Part II, Experiment

• Open today's Logger Pro and spreadsheet files. Place the 500-g mass on top of the hanger. Use the mass balance to determine the mass of the hanger plus the 500-g mass, and enter it into the appropriate yellow cell in the spreadsheet.

• Hang the spring from the equipment stand and stabilize the combined mass hanger and 500-g mass in its equilibrium position. Adjust the height of the bar of the equipment stand such that the bottom of the hanger is about 30 cm above the table.

• Remove the 500-g mass. Center the active element of the motion sensor below the hanger. Click on the Zero button in the top toolbar, just to the left of the green Collect button. This tells the motion sensor that you want the zero of position to correspond to the bottom of the hanger where the spring is unstretched, as it nearly is when it supports only the hanger.

• Gently replace the 500-g mass on the hanger such that the mass does not drop onto the motion sensor. Slowly return the hanger to its equilibrium position. Then pull it down from equilibrium by just a few centimeters and smoothly release it such that it moves only in the vertical direction. Collect data. You will see a sine wave. Click on the Curve-Fit button at the top of your screen. In the pop-up window, scroll down the list of functions until you read “A sin(Bt+C) + D” and choose it. Click on “Try Fit,” then “OK.” A solid black line will appear on the screen, along with the fitted values for A, B, C, and D. The value B is the radial frequency, which you should enter into the appropriate yellow cell in the spreadsheet.

• Undo the curve fit. Zoom in on one clean (i.e. no noise) period by highlighting the interesting region, right-clicking the screen, and choosing "Zoom In" on the top toolbar (magnifying glass with "+" sign). Use the Linear-Fit ("R=") function to find the slope at nine sets of three adjacent points, roughly equally spaced, of one period. Use the Examine ("X=") function to determine the position and time for each central point of your linear fits. Record the time, position, and velocity for each of your nine central points in the yellow cells of the spreadsheet. Copy and paste the fully annotated Logger-Pro plot that includes the nine different linear-fit data boxes into the answer box for Question 4 of your worksheet. You might need to decrease the size of the plot, such that the data boxes consume a larger portion of it.

• Enter the time of your first datum point of your sequence of data into the yellow time-offset cell of the spreadsheet in order to start the time axis at zero. If your fractional uncertainty (the standard deviation divided by the average, the bottom value of the green cells) is not less than 0.100, you should ask a lab instructor what might be wrong.

• Copy and paste the data within the bold outline of the spreadsheet into the area below Question 5 of your worksheet. Copy and paste the E(t) graph from the spreadsheet into the answer box for Question 6. Read the information in the green cells of the spreadsheet in order to individually report your result for E(t) in standard form for Question 7. Finally, individually answer the other parts of Question 7.

If all has gone well today, you have confirmed that mechanical energy is conserved for a mass on a spring.

Worksheet

Name and section number: **Partner's name and section number:**

1. Make free-body diagrams of a mass oscillating up and down on the end of a spring for three situations. Label the forces using mg and ky, the spring force. Also indicate if the situation could correspond to the top, middle, or bottom of the oscillation.

Equilibrium	Accelerating up	Accelerating down

2. If the zero for the potentials is the position of the mass when the spring is unstretched, write the gravitational and spring potentials and kinetic energies for the top, middle, and bottom positions when the mass is oscillating around its equilibrium position using m, g, y_t, y_m, y_b, v_m, and k. The subscripts refer to the top, middle, and bottom of the oscillation.

Top: U_g =	Middle: U_g =	Bottom: U_g =
U_s =	U_s =	U_s =
K =	K =	K =

3. Use the information above to write the total mechanical energy for each situation.

E_{top} =	E_{middle} =	E_{bottom} =

4. Insert into this box the annotated y(t) graph from Logger Pro, with data and boxes legible.

5. Insert into this space the outlined data from the spreadsheet.

6. Insert into this box the E(t) graph from the spreadsheet.

7. *Individually* report your result for E(t) in standard form. State whether or not mechanical energy is conserved and how the E(t) graph supports your conclusion. Describe how energy is converted from one form to another.

Our Analysis of this Laboratory

This lab focuses on conservation of energy in a spring mass system. The students set up a hanging spring mass system over a motion sensor to measure the change in potential and kinetic energy. The total mechanical energy, the sum of potential and kinetic energy, should not change throughout the oscillation. This experiment ran smoothly there were no problems with the procedure. This lab only had a few minor issues, mainly related to Logger Pro.

This is the 6th lab session the students attend. At this point they should be familiar enough with Logger Pro to the point that the software doesn't cause any major setbacks. Yet issues with the software still slowed the students down. First the students had trouble zeroing the motion sensor. After completing the experiment the students had a hard time creating a trend-line on their graph. If the students did not record enough data points then they couldn't create a trend-line using those points. One TA had to stop the lab to announce how to make a trend-line to the whole lab section. While the TA helped clarify this issue for the students, stopping the lab took a significant amount of time. Time is so precious to each of these labs, so losing time to a simple clarification issue is not ideal. Logger Pro has brought up clarification issues before, but after 4 labs the software should not slow the students down anymore.

The lab instructions created a few problems in this lab section as well. There is a point where the instructions are a little to vague. After the students set up the mass on the spring the instructions state to, "pull (the mass) down from equilibrium by just a few centimeters". However, if the students pull the mass just a little too far, then the system oscillates too fast for the sensor to accurately collect data. In this case "just a few centimeters" is too vague. If the students pulled the mass about 5 centimeters instead of say 3, then their data will be inaccurate. Clarifying that pulling the mass too far can create error is worth including in the instructions.

The conclusion of this set of lab instructions was also flawed. The lab instructions end by giving away a core concept to the students. The last sentence of the instructions reads, "If all has gone well today, you have confirmed that mechanical energy is conserved for a mass on a spring". This lab is set up for the students to prove that mechanical energy is conserved; it becomes much easier to prove if the instructions give away the conclusion. The point of this lab is for the students to use the experimental procedure to draw their own conclusion. In this case the lab instructions reveal that energy is conserved, but the students shouldn't know that yet. If the students knew that energy is conserved before the experimental process, then what are they working toward? The first sentence of the instructions reads, “You have likely heard that ‘energy is conserved.’ This lab explores whether or not that is actually true.”

The students are not exploring the truth to this law if the correct conclusion is given to them. The students should conduct an experiment and analyze data to reach their own conclusion. We suggest omitting the last sentence of the lab instructions, so the students aren’t proving a law they already know to be true.

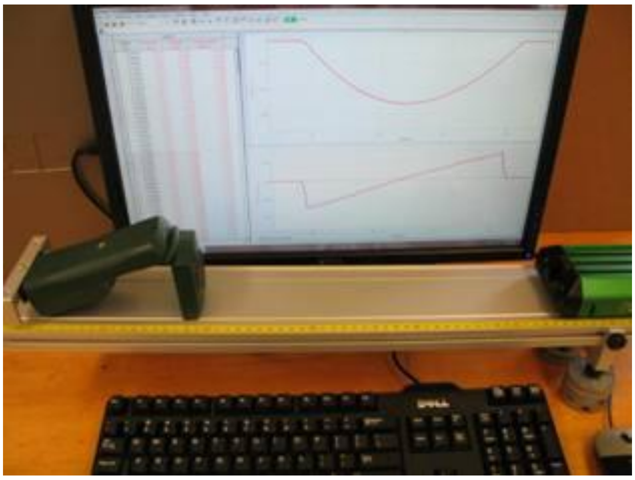
6. The Mass-Dependence of Friction

Procedure

Overview

You have developed many skills in lab so far: expressing uncertainties, setting up and using the equipment and software properly, understanding kinematics, and drawing free-body diagrams. You are ready to make a prediction and test it. You are to predict which variables associated with friction are dependent on mass and then run an experiment to see if you are correct.

There are two parts to this experiment. Part I concerns the theory and Part II, the experiment. This worksheet begins with questions from Part I that you should try before coming to lab. If you come to lab without having done Part I, go immediately to Part II and collect the raw data (#4 and the yellow boxes of #5 on the worksheet). Then return to Part I. The calculations of #5 can be done later, although of course it is preferable to finish while you are still in lab and can direct any questions you might have to your lab instructor.



Part I, Theory

•In your notebook or on a piece of scratch paper, draw free-body diagrams for a cart of mass m moving up and down a slope. The friction f is measurable. You should have two separate diagrams. Choose a coordinate system with the x-axis parallel to and pointing down the slope and with the y-axis perpendicular to the slope.

•Write out Newton's Second Law for each of the two directions for both situations. Use a_u for acceleration when the cart is moving up the slope and a_d for when it is moving down the slope. N stands for the normal force. The angle of the slope up from the horizontal is θ. Your equations should be expressed in terms of m, g, f, N, a_u, a_d, sin θ, and cos θ.

•Solve one of the equilibrium equations for N. Subtract one of the non-equilibrium equations from the other to solve for f. It will depend on m, a_u, and a_d. (The parameters that are known or can be measured in lab are m, g, a_u, a_d, and θ.) Then introduce $f = \mu N$ and solve for μ.

•Observe which equations depend on mass and which are independent of mass.

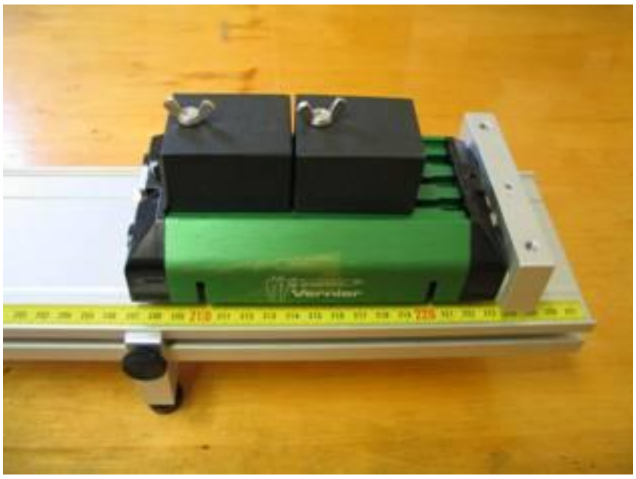
When you are satisfied with what you have predicted, open today's worksheet and answer Questions 1-3. You may copy and paste the provided label and arrows. Enlarge the drawing canvas if necessary, and similarly, you might find it easier to position the arrows if you undo object snapping by going to Drawing Tools → Align → Grid Settings. Check with your lab instructor to confirm that your free-body diagrams and equations are correct. Then move on to Part II.

Part II, Experiment

• Set up the equipment as for the kinematics experiment, where you detected the motion of a cart on a slightly sloped track. Open today's Logger Pro file.

• Determine the angle of the track using a ruler and your knowledge of trigonometry. Enter the value into the table in the worksheet. It is easiest to keep the angle of the track the same; enter the angle into all three rows corresponding to the three trials you are about to do.

• Your cart might or might not have one or two additional masses screwed to it, as in the pictures below. Measure the mass of your cart using a mass balance, as in the right-hand picture. The masses are attached to the cart by means of a bolt and wing-nut. Your lab instructor can show you the easiest way to secure them. Upon removing a mass, please replace the bolt in the hole and tighten the wing-nut so that these small parts do not get lost.



Above: cart and masses on track; Below: cart and masses on mass balance.

• Measure the accelerations of the cart as it moves up and down the slope, as you did for the kinematics experiment, in which you found acceleration as the slope of a Linear Fit ("R=" button in the upper toolbar) to the velocity. Display the standard deviation of the slope by right-clicking on the data box and choosing Show Uncertainty. Do this for the cart with no additional mass, one additional mass, and two additional masses.

• You may do the three measurements in any order. The accelerations for up and down the slope should be slightly different. (Do you understand why?)

• Copy and paste your graphs into Question 4 of the worksheet, making sure that you can see the data and read the data boxes, with standard deviations. You might need to decrease the size of the plots, such that the data boxes consume a larger portion of them. Fill in the table with the three mass values and the six accelerations. Type in the relevant units within the square brackets at the top of each column. Calculate N, f, and μ based on your equations. All values in the table should have four significant digits. Find the average of the three measurements for N, f, and μ.

- Logger Pro calculates the "sample standard deviations" of linear and quadratic fits. We have not yet told you how they are calculated. The equation is

$$sd = SQRT \{ [\sum_i (x_i - x_{ave})^2] / (n-1) \},$$

where x_i is an individual measurement, x_{ave} the average of the measurements, and n the number of measurements. Compute the standard deviation for the columns N, f, and μ, and then determine the fractional uncertainties, sd/ave. Of the three variables, two should have large fractional uncertainties, and one should have a small fractional uncertainty. (Why?)

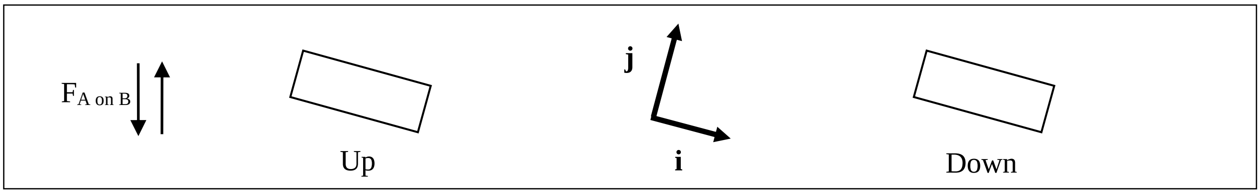
- In reporting your results for the last question on the worksheet, remember to follow the standard form that you learned in Part I of the uncertainties experiment. Please answer the last question individually, in your own words.

If all has gone well today, you have made some predictions about the dependence of the friction variables N, f, and μ on mass and verified your predictions experimentally.

Worksheet

Name and section number:
Partner's name and section number:

1. Make free-body diagrams of a cart moving up and down the track. Label the forces.



2. Based on the above, write out Newton's Second Law for each direction for both situations.

Up: $\Sigma F_x = ma_u =$	Down: $\Sigma F_x = ma_d =$
$\Sigma F_y = 0 =$	$\Sigma F_y = 0 =$

3. Solve the above equations for N, f, and μ. Answers must be in terms of m, g, a_u, a_d, and θ.

N =	f =	μ =

4. Insert into the box the $v_x(t)$ graphs for the three measurements, with data and boxes readable.

a)

b)

c)

5. Fill in this table, stating the units within the square brackets, and using four significant figures. If you are pressed for time, collect data now (yellow boxes) and calculate later (green).

Trial	θ []	m []	a_u []	a_d []	N []	f []	μ []
1							
2							
3							
				Average:			
				Std dev:			
				Sd/ave:			

6. *In your own words,* summarize your results for N, f, and μ, using the standard form that you learned in Experiment 0. Explain why the fractional uncertainty, sd/ave, for one variable is so much different than for the other two.

Our Analysis of this Laboratory

The Mass Dependence of Friction lab features an experiment with a cart on a track. The students are told to measure the mass of the cart on a balance and place the cart on a downward sloping track. A string is run through a pulley at the top of the track. The cart is attached to one end of the string, and a mass hanger is attached to the other. By adjusting the amount of mass on the hanger, the rate at which the cart moves down the track can be adjusted. Using Logger Pro and a motion sensor, students measure the acceleration of the cart as it moves down the track. Before coming to lab, students draw force diagrams for the cart on the track. This diagram is then used to find net force. Then, they set up the force equation, F=ma, to calculate the friction coefficient μ. Lastly, the students repeat that same procedure but with a larger hanging mass so that the cart accelerates up the track.

The first problem with the instructions is that the students were instructed to read through Part 1 but only one group had done so. Part 1 of the instructions is about creating a force diagram for the cart to determine net force. Students were supposed to come into the lab with a force diagram already done, but many of them did not. In fact, so many students were not prepared with a force diagram that the TA had to draw one on the board, which was a time consuming process. The TA should not have appeased the students with a force diagram. It is on the students to draw the force diagram themselves, if they are having trouble they can ask for assistance. The instructions state that part 1 should be completed before coming to lab and that any questions regarding it should be addressed at the beginning of the lab period. We suggest making pre-reading labs ahead of time more of a priority. In doing so, students would be better able to complete the experiment within the allotted 50 minutes.

By now the students are familiar with the Logger Pro software and therefore there were fewer questions about how to use the software. Students use Logger Pro to create a velocity vs. time graph, with which they derive the acceleration of the cart. Students are also asked to find standard deviation of their graph and present the data in their worksheet. The Logger Pro software is good for this lab because it does not do too much for the students; it only presents raw data that the students need to interpret on their own. The instructions also do a good job of clarifying what Logger Pro does to find the standard deviation so the students understand how it is found instead of being presented a number without context.

This lab is time consuming, but the experiment is worth it. We think this lab was one of the better labs. It touches on some important lessons -- such as drawing a force diagram, setting up and running a successful experiment, collecting data, and analyzing that data. The experiment is very effective at demonstrating the forces acting on the cart as it moves along a track. The worksheet also does a good job evaluating if the students ran a successful experiment and analyzed the data correctly. The instructions were also informative and easy to follow.

7. The Rigid Pendulum

Procedure

Overview:

The objectives of this laboratory are to determine

i) the functional dependence of the period of a pendulum on the pendulum's moment of inertia, mass, and the position of its center of mass, both experimentally and theoretically

ii) an experimental value for the acceleration of gravity.

Equipment: Equipment stand about one meter high with a hook
Meter-stick with holes
Masses and wire
Stopwatch
Mass balance

Procedure

Open the spreadsheet. Determine the mass of the meter-stick and the meter stick's length below its pivot point, and enter the values into the appropriate yellow cells in the spreadsheet. Hang the meter-stick from the hook on the equipment stand and measure its period. Enter the period into the appropriate yellow cell in the spreadsheet (Case 1, meter-stick only).

Note that the meter-stick has three sets of pairs of small holes. Add mass to the meter-stick with the wire. Record the mass, m_i, and its distance, r_i, from the pivot point, and measure the period again. Enter the values into the spreadsheet. Do this for a total of four different combinations of m_i and r_i (Cases 2-5). You may use more than one set of holes at a time.

Observe that the spreadsheet returns values not only for the slope and its standard deviation, but also for the intercept and its standard deviation.

Include both the table on the first sheet and the plot in the data section of your lab reports. In the results section, you are to derive the expression for the period of a rigid pendulum, starting with a free-body diagram of the pendulum and using Newton's Second Law for rotation. You are on the right track if you find this intermediate expression:

$$I\, d^2\theta/dt^2 = -\, MR_{cm}\, g \sin\theta,$$

after which you may assume that θ is small, such that $\sin\theta \approx \theta$. Here I is the moment of inertia of the meter stick when pivoted around one end, M is the mass of the meter stick, and R_{cm} is the distance from the pivot point to the meter stick's center of mass. For each experiment, you will need to calculate I and R_{cm}.

You will then compare your theoretical expression for the period T, as a function of I, M, and Rcm, with your experimental values for T, I, M and R_{cm}. How do you make the comparison? You use a log-log plot.

As a reminder of log-log plots, if one starts with an arbitrary power law

$$f(p,q) = A\, p^m$$

with p as a variable, m as a power index, and A as an object that is independent of p, and takes the logarithm of the equation, the expression becomes

$$\log f(p,q) = m \log p + A.$$

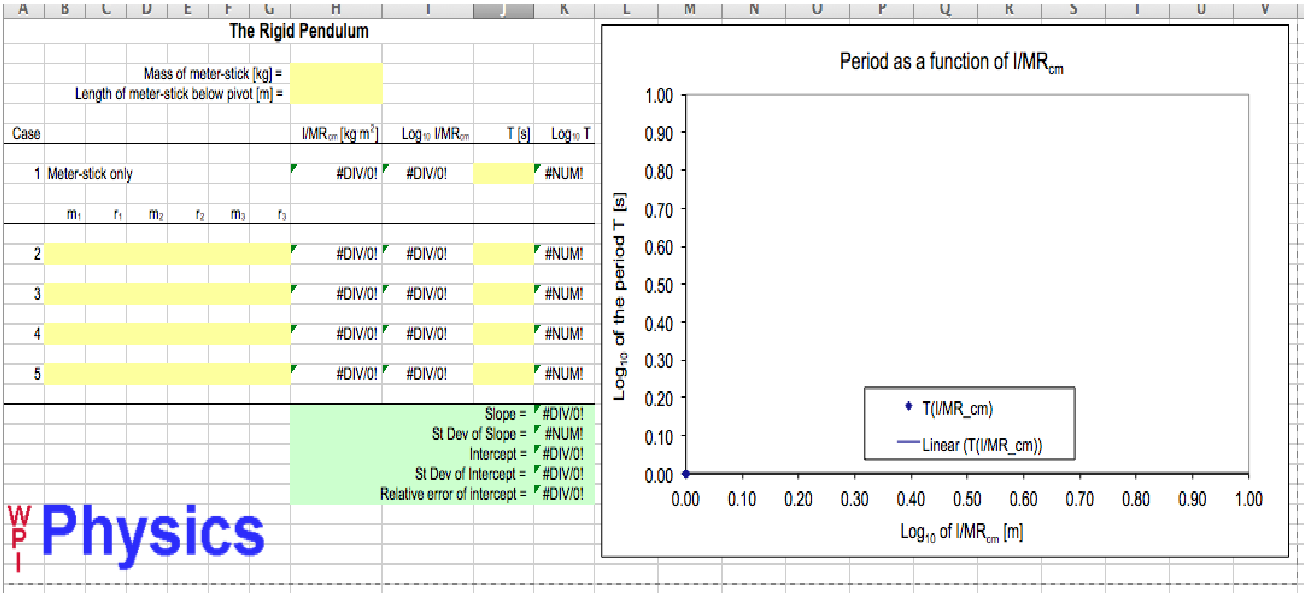
A could depend on things other than p. The above can be rewritten with $F = \log f(p,q)$, $x = \log p$, and $b = A$ as

$$F = m\, x + b.$$

which is the equation for a straight line. A fit of experimental data (e.g., log f) on a log-log plot to the independent variable (here a function of I, M, and R) gives the power-law dependence of F (period T) on the independent variable. The intercept b gives the multiplicative constant (proportional to g) that relates $(I/MR_{cm})^m$ to T.

As usual, report your results and standard deviations to the appropriate number of significant digits.

Data Sheet



Our Analysis of this Laboratory

This lab explores the period of a physical pendulum. The students start the experiment by weighing a meter stick. The meter stick is then hung from a hook so that it acts as a physical pendulum. Then the students record the period of the pendulum, after recording the mass, length (1 meter), and angle. After gathering experimental data, the students complete computations to discover the period equation for a physical pendulum as it relates to the pendulums moment of inertia. Since the experiment is so simple this lab didn't experience any significant setbacks. However, there were a few minor issues that are worth mentioning.

The equipment for this lab was slightly unsatisfactory. This lab calls for the students to measure the period of the pendulum, but they are not given stopwatches. Most students had their smart-phone with them, which they used to record. The Physics department should supply the students with the equipment to complete the experiment it shouldn't be on the students. It may seem insignificant but what if a group of students didn't bring their phones? It cannot be assumed that the students will be prepared with their own stopwatch. We suggest supplying the students with stopwatches for this lab.

Another problem in this lab was that the students were taking inaccurate measurements of the pendulum's period. The students were trying to start their timers as another student let go of the meter stick to start the period measurement. Attempting to start the timer as the pendulum starts its oscillation creates unnecessary error. It is much easier to start the timer and then observe the time at which the pendulum starts its motion. This suggestion should be added to the lab instructions to clarify the best way to measure period for the students.

PH-1120/1121 Laboratories

1. The Electric Field

Procedure

Overview

Purpose:
The purpose of this experiment is to acquaint you with the properties and behavior of the electric fields.

General Experimental Information:
The electric field is a vector quantity represented by an arrow of length proportional to the size of the electric field and a direction parallel to that of the electric field, both evaluated at the point where the tail of the arrow is located.

There are only THREE parameters to keep in mind in figuring out the size and direction of the electric field at a point due to a nearby electric point charge – the POLARITY of the charge (positive or negative), the MAGNITUDE |q| of the charge, and the DISTANCE r between the point-charge location and the point where the electric field is being evaluated. The size of the electric field (the length of the arrow representing that electric field) at that point of evaluation is directly proportional to |q| and inversely proportional to r2. The electric field direction points directly away from a positive point charge and directed toward a negative point charge. In a situation involving two or more point charges, the analysis simply involves the linear superposition of the individual effects of each point charge separately, and that's a REALLY important aspect of this laboratory exercise.

Tasks at Hand:
In this experiment you will first analyze the electric field associated with individual point charges, and then you will analyze the electric field associated with specific arrangements of two or more point charges.

General Course Information:
And now, in closing, we must turn to some housekeeping details. In each of these PH 1120 labs, you should find two additional documents on the bottom of main page: a PH 1120 Lab Data Sheet, and a PH 1120 Lab Report. The Data Sheet will often prove very useful either for practice or collecting Data to be used to complete the Lab Report. The Data Sheet need not be turned in at the end of your Lab session. The second document, entitled Lab Report, is the one document to be submitted for each respective experiment. It must be submitted on-line by midnight of the corresponding lab day and will be graded and counted toward your lab grade in PH 1120. The lab report will generally involve some short-answer questions, calculations based on the processing of raw data, and critical thinking. You may work on your Lab Report anytime after your experimental work is finished and your Data Sheet is submitted, even during the lab session if time permits. Additionally, there will often be one or more other documents, such as a Vernier Logger Pro graphical template, appropriate to the task at hand for that labeled part.

The point of all this is that Data Sheets are for use during the lab sessions, and the Lab Reports are for the more reflective reporting of what you got out of each experiment.

This concludes the Overview. Now you may proceed with the Data Sheet.

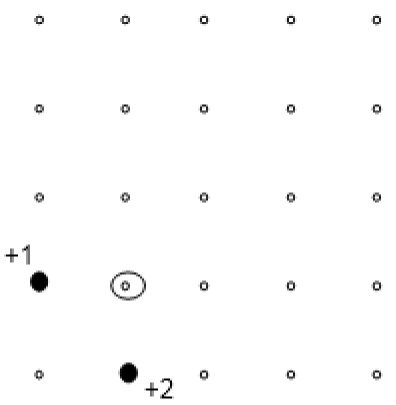
Data Sheet

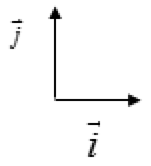
The Electric Field - Data

Name: ________, Partner: _________

Section: ________, Date: __________

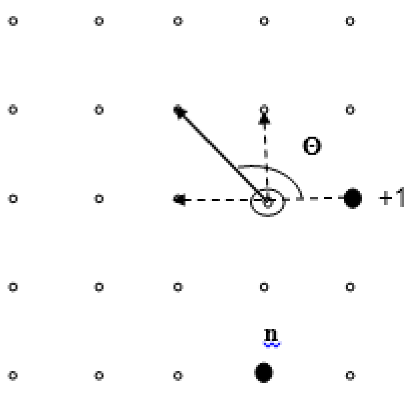
1)





L =
Θ =

2)

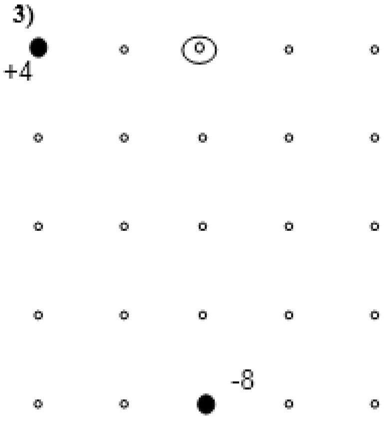


n =

L = $\sqrt{2}$ = 1.41

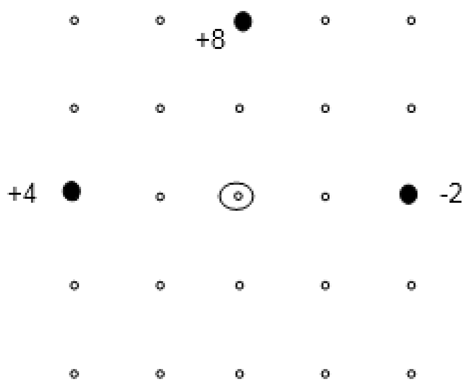
Θ = $\tan^{-1}\left(\frac{1}{-1}\right) = 135.0°$

3)



L =
Θ =

4)



L=
Θ =

Worksheet

The Electric Field – Lab Report
(Due by <u>midnight</u> of the day of the Lab)

For Full Marks you must show your work. Repeated calculations need only be presented once.

Name: ___________,

Partner__________

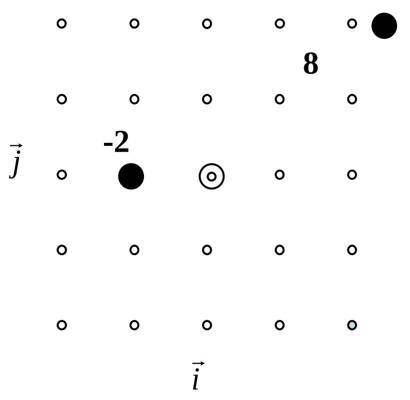
Section: __________,

Date____________

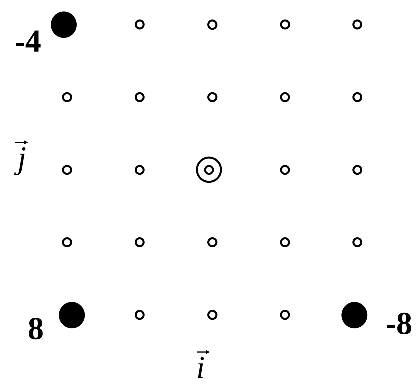
Note: It is always important to show your work. You must always show your equations and calculations. This true for all Lab work for First Year Physics Courses!

1. Indicate Two different ways to set-up a situations that would result in $\vec{E}$ -field vectors that are **4** grid units long.

2. Determine the length and angular orientation of the electric field at the indicated point resulting from the given 2-charge superposition.



3. Determine the length and angular orientation of the electric field at the indicated point resulting from the given 3-charge superposition.



Our Analysis of this Laboratory

The electric field laboratory is the first laboratory in the PH-1120 and PH-1121 classes. While the intent of the laboratory is to familiarize students with the electric field, students are not given any experiment to conduct. Instead, students are given a worksheet and told to submit when finished. Therefore, there is a missed opportunity to conduct an actual experiment and teach students about electric fields.

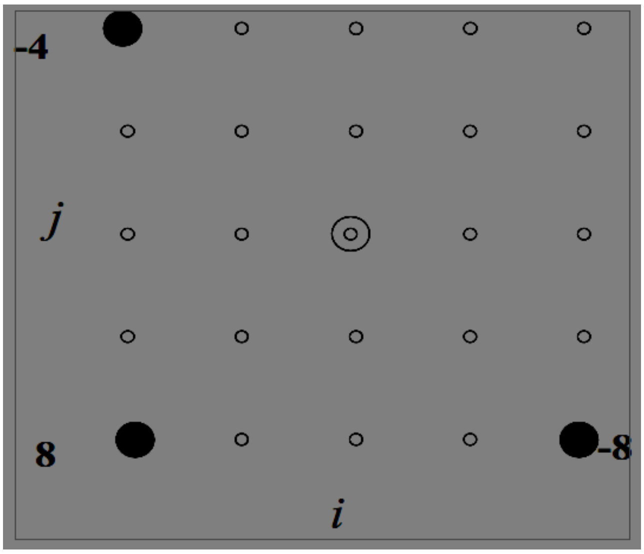
At the beginning of the lab section, the TA polled the class and asked how many students had taken PH-1110 or PH-1111. Approximately three quarters of the class (26 students) had previously taken a physics course at WPI. As a result, most students were familiar with the lab submission process and the have also used the logger software.

There were no instructions included with the data sheet. In order to show students how to complete the do so, the TA needed to do an example problem on the board. However, the biggest problem with the assignment is that it teaches students about electric field as if an electric field only exists in two dimensions. In reality, by contrast, electric fields exist in all three dimensions – and the lesson should be adjusted to teach students about electric fields in a more realistic way.

Upon opening the lab questions, two groups noted that they were unable to make changes to the lab report. The TAs explained that before students can edit the file, they need to click "checkout". This is more of a difficulty with Microsoft Word, but enough students had trouble with it that we felt it deserved mentioning.

Two lab groups had difficulty with the question three on the lab report:

Determine the length and angular orientation of the electric field at the indicated point resulting *from the given 3-charge superposition.*



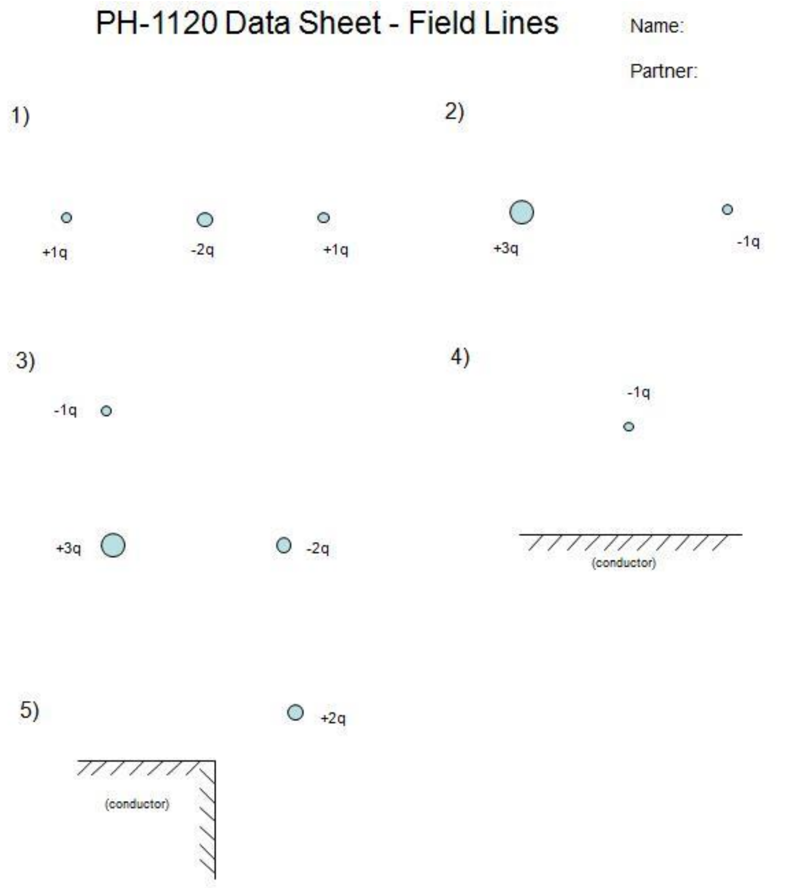
Firstly, the question should be reworded. 'Length' is not an appropriate term to describe an electric field. This question shows a field with three charges and asks students to calculate the net field. To help students with this question, the TA showed another example on the board. The correct approach is to apply Coulombs law, separate the charges into their components, and sum the results. This seemed to answer the student questions, but we were surprised that there was so much difficulty with this calculation.

2. The Electric Field and Field Lines

Procedure

Purpose: The purpose of this experiment is to acquaint you with electric field lines.

Data Sheet



For each of the 5 charge distributions above:

a) Draw and appropriate Field line diagram
b) On your diagram, put a point where the Electric Field is relatively "strong" and attach an arrow showing the electric Field direction.
c) Similarly on your diagram show a Field vector for a relatively weak point.

Worksheet

WPI Physics

PH 1120 - Electric Fields & Field Lines Lab Report

Equations are useful and often the only solution to a full explanation to a question in a Lab Report.

Name:_____________; Partner:______________
Section:____________; Date:______________

1. You have 3 point charges in your region of interest: +5 nC, –6 nC, and +10 nC. Specify the number of lines you would associate with each charge, and specify whether they originate at or terminate at each respective charge.

2. Repeat Problem #1 above, this time with the 4 point charges: –5 nC, –2 nC, +3 nC, and –20 nC.

3. In starting to draw a field line diagram, you should space the lines symmetrically about each respective point charge as though the other point charges do not matter. Explain the reasoning behind this.

4. Given the way in which field lines represent important attributes of the electric field, explain the manner in which this representation is inconsistent if two field lines were allowed to cross.

5. When drawing field lines near conductors (conductors being filled with charge – electrons – that are free to move around inside the conductor), explain why no field lines are able to penetrate into the conductor (under electrostatic conditions).

Our Analysis of this Laboratory

The Electric Field and Field Lines laboratory focuses on familiarizing students with drawing electric field lines. We immediately noticed that there are no instructions in this lab, and there is no experiment to complete. Students were simply given a "datasheet" (attached below) and a worksheet to fill out. We thought that this was an inappropriate use of the lab period. Physics labs present a unique opportunity to conduct an experiment that students may otherwise not be able to do themselves. Simply giving students a worksheet to fill out defeats the purpose of the structured lab meetings.

This lab, like the previous, also attempts to portray the electric field as a two dimensional effect. For the sake of accuracy, the lab should make some attempt to make it clear to students that the electric field operates in all three dimensions.

We noticed that three or four students left the lab about ten minutes into the hour, and about half had left by 25 minutes past. Very few students felt a need to attend the full length of the lab.

3. Determining Resistance

Procedure

Overview

Goal: First, examine electric potentials. Second, simple use of Ohm's Law using an IV curve to determine resistance.

Objective:

1**)** To use a simple circuit to measure the value of a carbon resistor, complete with uncertainty.

Purpose:

1) To illustrate the difference between the scalar electric potential and the vector electric field.

2) To touch base with building a simple circuit and making measurements of electrical properties of a circuit.

Electric potential, like the electric field, is an important quantity associated with an electrical charge and collections of electrical charges. In contrast to the vector electric field, however, electric potential is a scalar quantity (meaning that it is characterized by a single number, which can be positive, negative, or zero). It is easily measured with a volt meter, a device with which you may already be familiar. Batteries, for example, are rated in terms of voltage – a 1.5 V battery has a positive terminal that is approximately 1.5 V higher than the negative terminal, and that potential difference (easily measured by a voltmeter) makes it possible for a battery to cause electrical charges to flow through circuit elements such as light bulb filaments (in order to generate light) or cell phone circuitry (in order to enable the cell phone to make and receive phone calls).

Our interest in the carbon resistor is not so much based on its ubiquitous presence in essentially every electrical circuit ever designed, but on its linearity. The voltage difference across a carbon resistor is linearly proportional to the resulting current flow through the resistor. This relationship is known as Ohm's law: V = IR, where V is the voltage across the resistor (measured in volts), I is the current through the resistor (measured in amperes, or simply, amps), and R is the resistance of the resistor (measured in ohms = volts/amps = V/A = Ω). The magic of the carbon resistor is that its resistance value R is remarkably constant over its whole operational range. Basically, you will be using this constant-resistance property of the carbon resistor as a vehicle for learning a bit more about the meaning of measurement uncertainties and a bit more about how uncertainties are handled in real-world measurement situations.

Procedure:

Important note: Be sure **NEVER** to exceed 6.0 V across the Vernier Differential Voltage meter **OR** 0.6 A through the Vernier Current meter, each as read on their respective meters on the Vernier template used in the following experiment. As well, before turning on the power supply make certain that the Volatage [sic] Adjust knob is turned completely counter-clockwise. In its turn, the Current Limit knob should be set to the middle of its range.

In this part, you are going to determine the resistance of a carbon resistor by making electrical voltage and current measurements. (Ohm's law: V = IR; R measured in ohms = volts/amp = V/A = Ω.)

First connect up the circuit as described on the white board by your lab instructor, using the designated resistor R3, R4, R5 or R6. After opening the Ohm's Law Vernier template, make sure that the voltage supply is set to zero, then zero the reading. Now start collectingdata [sic], then record 9 datum points that appear on the I-V graph, starting with a voltage of 0 and increasing by approximately 0.5-ish V increments up to a maximum value of about 4.0 V. After recording the 9th point, stop the data collection.

The resistance value is the slope of the line obtained by fitting a straight line to the set of 9 points. Perform a least squares fit and a dialog box will open giving, among other things, the value of the slope of the straight line (which is the resistance value!). **Please note how closely the nine points come to fitting a perfect straight line – a testament to how constant the resistance of a carbon resistor is over a range of voltage/current values!** Right-click on that dialog box, and when a new box opens, select both the 5-digit option and the "show uncertainty" choices. Write down on your Data Sheet the resistance value and uncertainty including all digits presented. Once the data are recorded, select "Data" from the main menu choices and click "Clear All Data."

Record three more data sets in exactly the same way as above for the same resistor. **Remember to always** turn down the voltage to 0, and zero the sensor between data sets.

When you have collected and written down 4 slope/uncertainty pairs, then open the Average And Standard Deviation
Excel file, enter the 4 5-digit slope values without uncertainties where indicated, and you will automatically be given the average and standard deviation of that set of 4 resistance values, which you should transcribe on your Data Sheet. If your experiment was properly and carefully performed, you should find that the calculated standard deviation of the 4-element data set is of the same **order of magnitude** as the individual slope uncertainties recorded from each individual experiment, and any difference between an individual slope-value and the 4-slope average is generally less than two times the sum of the 4-set uncertainty and any individual slope uncertainty.

Technically, the slope average and standard deviation of a set of several identical repetitions of the same measurement (especially if the repetition number is **far** greater than 4) is the most correct statement of the "true" slope value, but this experiment is intended to show you that **one** measurement **with uncertainty** can provide roughly comparable information. And briefly stated, this least-squares straight-line fitting approach is a common way that data are analyzed, out in real world Industrial measurements. In subsequent experiments you will be using this approach to accomplish some significant data analysis, so please don't promptly forget everything you did or learned today.

Worksheet

WPI Physics

PH 1120 - Electric Potential & Determining Resistance Lab Report

Remember to use equations to show your work

Your Name: ?? Section: ??
Partner's Name: ?? Date ??

1. Can two equipotential surfaces with different potential values ever intersect or cross? Answer and explain briefly.

2. Do the numerical values of equipotentials get larger or smaller the closer the equipotentials are to a negative charge? Answer and explain briefly.

3. Write each of the four least-squares results for the resistance (slope) measurements, including the uncertainties, in standard form. Also, write down the average ± standard deviation obtained from Excel in standard form.

Resistance Values (Ohms)	Uncertainty (±)

Average (Ohms)	Standard Deviation (±)

4. In the Lab Overview to Part 2, the claim was made that the Excel standard deviation of the 4-element data set of slopes should be of the same order of magnitude as the individual slope uncertainties recorded from each separate experiment. Is it? Also as part of your answer, calculate the ratio of the two quantities mentioned above, and state the result.

5. For the slope-value with the smallest uncertainty, determine the magnitude of the difference between that slope-value and the 4-slope Excel average. Now compare this number to twice the magnitude of the sum of the 4-set uncertainty and the individual slope uncertainty corresponding to your chosen slope- value. Is it true that the latter quantity is larger than the first?

Our Analysis of this Laboratory

In the *Determining Resistance* laboratory, students are instructed to create a simple circuit consisting of one resistor and then observe the voltage drop across the resistor. Students are provided an ammeter, voltmeter, a circuit board, and an assortment of wires and resistors. This lab functions as an introduction to circuit wiring and Logger Pro

In order to collect all of the data in the provided 50 minutes, students need to work quickly. The TAs were very busy throughout the lab period, and spent the first twenty minutes helping students set up their circuits. While TA intervention certainly made it possible for many groups to finish on time, we are worried that too much intervention will make students dependent on the TAs. When students are forced to set up the circuit themselves, they learn a great deal more about how it works. We are concerned that students are missing out on an excellent learning opportunity. It is critical that students learn how these circuits work because later labs (Lab 5 in particular) require much more complicated wiring and there is simply not enough time for the TAs to help every group. We think that the first two labs should be combined (or simply removed), and that this time should instead be used to help familiarize students with circuit diagrams and wiring.

Despite the simplicity of the circuit, nearly every group had difficulty setting it up correctly. We suspect that this is many students' first time working with circuit diagrams.

Additionally, this is the first electricity and magnetism lab that requires students to collect data with Logger Pro. While most of the class had previously used the software in PH-1110 or PH-1111, most students were not familiar with the sensors used in this lab.

Students were told to first set up their circuit in accordance with the diagram in the instructions, and then verify with a TA that their wiring is correct. While this approach certainly helped students complete the lab on time, it resulted in a lot of "hand holding" and we are concerned that students will need to rely on the TAs too much in later labs when the circuits become more complicated. In addition, we overheard the lead TA tell the assistant TA that he had set a group's circuit up incorrectly. This was concerning to see, but it is clear proof that having both an assistant and lead TA in labs is an effective strategy.

One group's power supply broke and needed to be replaced for them to continue. We were not able to determine if the failure was a result of improper use of the equipment or if the power supply failed on its own. However, this was the group that the TA had incorrectly help set up.

Two groups helped one another with Logger Pro. This collaboration was nice to see, and allowed the TAs to help other groups. Especially given WPI's emphasis on group collaboration, we think that this teamwork should be encouraged more.

The instructions state that students are to connect the wires to "the designated resistor R3, R4, R5, or R6" however the TA's told the students to choose either the 51 Ohm resistor or the 68 Ohm resistor.

Students are asked to report their results in standard form. We observed that four groups had difficulty with doing so. The TAs recommended that students watch the video that is linked in the PH-1110 Lab 0 instructions. Many students followed this advice, but two groups commented that the video will only load in Internet Explorer (and not Google Chrome).

Four groups were still working when lab time expired.

4. Electric Potential and RC Discharge

Procedure

Overview

There is still one more property, namely "Potential difference," that you will work through because it is so directly relevant to lecture discussions about the electric potential. Due to the fact that the electrostatic field is a conservative field, the potential difference encountered in moving from one point to another depends only on the location of the end points and not on the path followed from start to finish. Add to that the fact that electric potential is a scalar quantity, potential difference promises to be easy to work with. There is one complication, and that is the fact that charge polarity must be taken into account because charges come in positive and negative varieties.

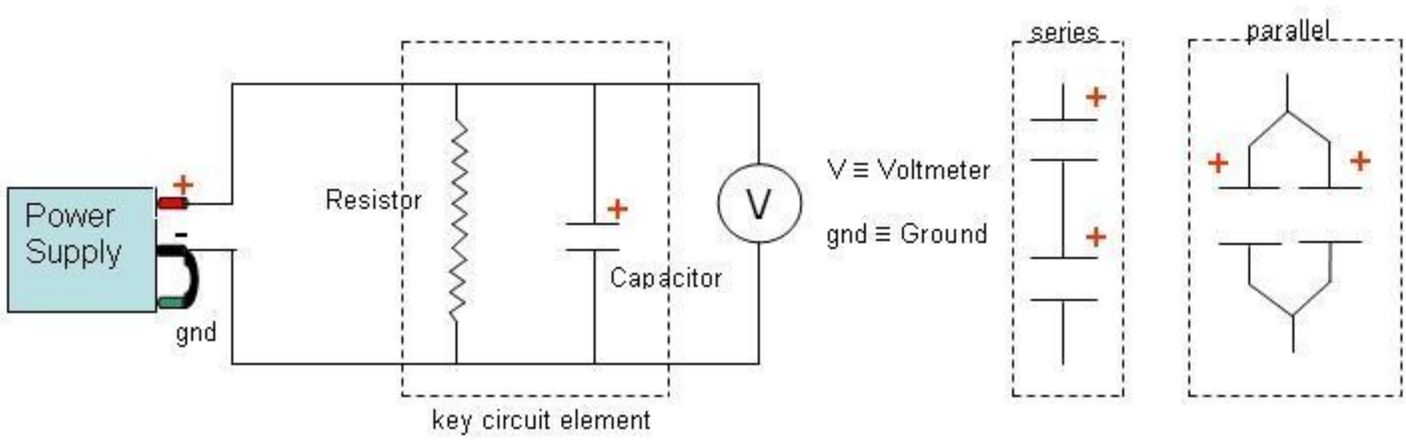
Another important property is capacitance, or the ability of an object to hold an electrical charge. A capacitor is an important electrical component that can hold separated amounts of positive and negative charges. Capacitors are as common in many electrical circuits as resistors. One important task to learn is the set of rules for determining the equivalent capacitance of a set of individual capacitors in parallel and/or series arrangements with one another.

Part 1 - Electric Potential:

Calculate the potential at a +1 point charge (1.00) and at a second point one grid length directly away with a +0.5 charge (0.50). Now, calculate the potential difference associated with moving from the first point to the second. Remember that a potential difference between two points is always defined to be $V_{final} - V_{initial}$.[Note: p762, 13th edition Young & Freedman]

Part 2 - RC Discharge:

The resistance of carbon resistors is relatively easy to measure, as you learned in the previous experiment, the direct measurement of capacitance requires special equipment that we are not going to duplicate at some 30 separate PH 1120 lab stations. You are going to use a special approach especially suited to our Vernier equipment, with the emphasis on measuring the equivalent capacitance value of parallel and series combinations of capacitors as discussed in lecture. Note that the voltmeter is connect "across" the capacitor; it is in parallel with the capacitor.



As you will hear in lecture, a charged capacitor connected to a resistor discharges through the resistor in such a way that the voltage across the capacitor decreases with time according to the equation

$$V(t) = V_o e^{-t/(RC)},$$

where V_o is the initial voltage across the capacitor at time t = 0, R is the resistance value of the resistor, and C is the capacitance value of the capacitor. Logger Pro is able to plot both V(t) and ln(|V(t)|) = constant – t/(RC). Whereas V(t) is an exponential, the natural log of the absolute value of V(t) is a straight line of slope magnitude

$$|\text{slope}| = 1/(RC).$$

You will be using an R = 22,000 Ω ± 5% resistor in this experiment, and you will be measuring the slope of the natural log of the time-varying voltage across the capacitor, which means that you can solve for C as

$$C = 1/(R\cdot|\text{slope}|).$$

Here is the procedure to follow:

Hook up the circuit with only one capacitor connected in the circuit as described by your Lab Instructor. BE SURE to connect the capacitor into the circuit properly with the + end (if the capacitor has a polarization preference) connected to the positive side of the voltage supply. Open the RC Logger Pro template, and turn on the power supply (making sure that the voltage control knob is turned CCW all the way to its zero position). Now, zero the reading and then turn up the voltage of the power supply until the voltage meter reads about 5.0 V.

Start collecting data and quickly prepare to disconnect the + voltage clip lead from the circuit once the “Collect” button turns red and you see data begin to collect, forming horizontal lines on the graph. As soon as you disconnect the + voltage, the capacitor will begin to discharge through the resistor, and you will see the two voltage graphs being recorded suddenly change profiles- one following an exponential profile with time, while the other follows a downward-sloped straight line. Data collection automatically stops after 10 seconds. You should turn down the voltage supply to 0 at this point.

Highlight from near the top of the downward-sloped straight line to a point where that graph begins getting noisy, and perform a least-squares fit. When the “Select Columns” dialog box opens deselect the “Latest Potential” choice so that only straight-line graph will be involved when you close the dialog box. Then right click the least-squares data box so that you can select the “Linear Fit Options” where you will select 5 significant figures and “Show Uncertainty.” Write down your slope magnitude and uncertainty values (See Note Below). The reciprocal of the quantity "slope magnitude" times 22,000 Ω gives the value of the capacitor **in farads (F)**, the SI unit for capacitance.

Note: What you should do for uncertainty in capacitance is simply to calculate the 4 capacitance values, using the slope magnitudes and 22,000 Ω. Take 5% of each resultant as the uncertainty, and then express each capacitance value in industry-standard format.

Now repeat the experiment with the first capacitor replaced by the second capacitor found at your station, then both in PARALLEL, and finally with both in SERIES. Be careful to connect the positive side of the capacitor (if polarized) to the positive side of the voltage supply and zero the reading (with the voltage supply still at zero) between each experiment.

Worksheet

WPI Physics

Electric Potential and RC Discharge -- Lab Report

Your Name: ? Partner's Name: ?
Section: ? Date: ?

As always show your mathematical work with appropriate equations.

2. Using a single point charge of –2, indicate where (how many grid units away) you would place initial and final points in order to have a potential difference of –3 V. [Note: $\Delta V = -\left(\frac{U_b}{q_0} - \frac{U_a}{q_0}\right) = q\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$, begin at page p761and continue through p 770, 13th edition Young & Freedman and remember that k=1 for our purposes.]

3. Using a single point charge of –2, indicate where (how many grid units away) you would place initial and final points in order to have a potential difference of +3 V.

4. Using a single point charge of +8, indicate where (how many grid units away) you would place initial and final points in order to have a potential difference of –6 V.

5. Using a single point charge of +8, indicate where (how many grid units away) you would place initial and final points in order to have a potential difference of +6 V.

6. Now for some error analysis of the capacitor measurement situation:

   [Note: The slope-uncertainty that you recorded in each of the four experiments should have been within about 0.1% of the corresponding slope magnitude, and certainly less than 0.5% in all cases. The resistor, unfortunately, is too large to be measured using the approach of Experiment #3, so we have to go with the manufacturer's rating, which is ±5% (that's what the gold band at one end of the 22,000 Ω resistor means). Five percent is SO much larger than the slope uncertainty that anything calculated from R (or even 1/R) is automatically 5% uncertain. (The slope uncertainty can legitimately be disregarded in comparison with the resistors rated uncertainty!)]

   What you should do for this Problem #5 is simply calculate the 4 capacitance values, using the slope magnitudes and 22,000 Ω. Take 5% of each resultant as the uncertainty, and then express each capacitance value in industry-standard format (one significant figure in the uncertainty unless the lead digit is 1, in which case you use two significant figures, and in either case you express the main value to the same level of significance as the uncertainty – hundreds, tenths, ones, tens, …, whatever it is).

7. Now calculate the parallel and series capacitance based on slope values and compare those results to values calculated from the slope values of the individual capacitors. Are your measured parallel and series capacitances equivalent to your calculated values, taking uncertainty into account? With any luck, they should be!!!

Our Analysis of this Laboratory

The electric potential and RC discharge lab focuses on familiarizing students with the property of "potential difference".

In this lab, students are given a circuit board and some capacitors and are asked to observe the capacitors discharging when the voltage is disconnected. Students are asked to connect a varying number of capacitors in different arrangements:

1. C1
2. C2
3. C1 and C2 in series
4. C1 and C2 in parallel

While the TAs were eager to help students get set up, they were doing too much of the work. We watched on a few separate occasions where the TA rewired the students' entire board while the students watched.

The instructions tell students, "As soon as you disconnect the + voltage, the capacitor will begin to discharge through the resistor, and you will see the two voltage graphs being recorded suddenly change profiles- one following an exponential profile with time, while the other follows a downward-sloped straight line". There are a few problems with this statement:

1. It makes the lab unexciting
2. There is no "experiment" if students are given the answer
3. Students should draw a conclusion from their data, not the other way around

The lab report sheet suffered from the same problem:

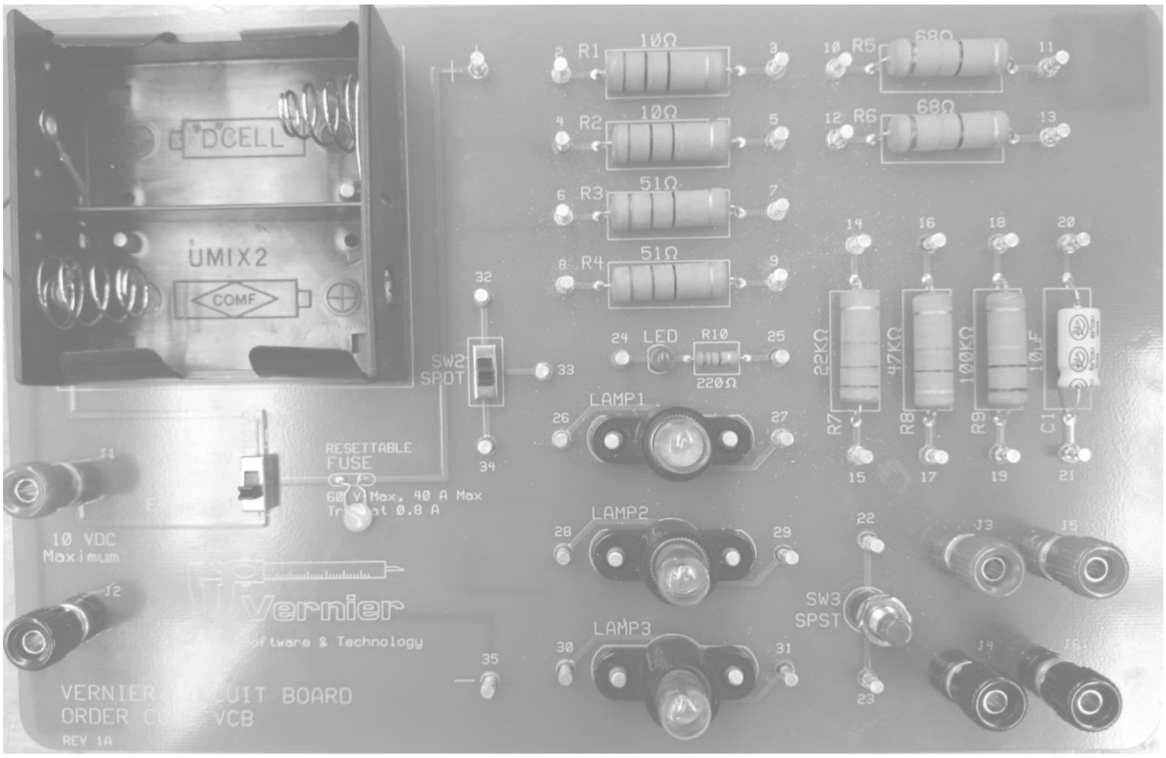
> "Now calculate the parallel and series capacitance based on slope values and compare those results to values calculated from the slope values of the individual capacitors. **Are your measured parallel and series capacitances equivalent to your calculated values, taking uncertainty into account? With any luck, they should be!!!**"

Additionally, the first four questions of the lab report deal with the same concept. Adding some variety to the questions and asking students to analyze their findings in the lab report would be more beneficial. These questions, although related to potential difference, ask students to calculate how far away two plates of a capacitor should be in order to have a specified potential difference. Since this was not a focus of the lab, these questions seem out of place. Below is an example question from the lab report:

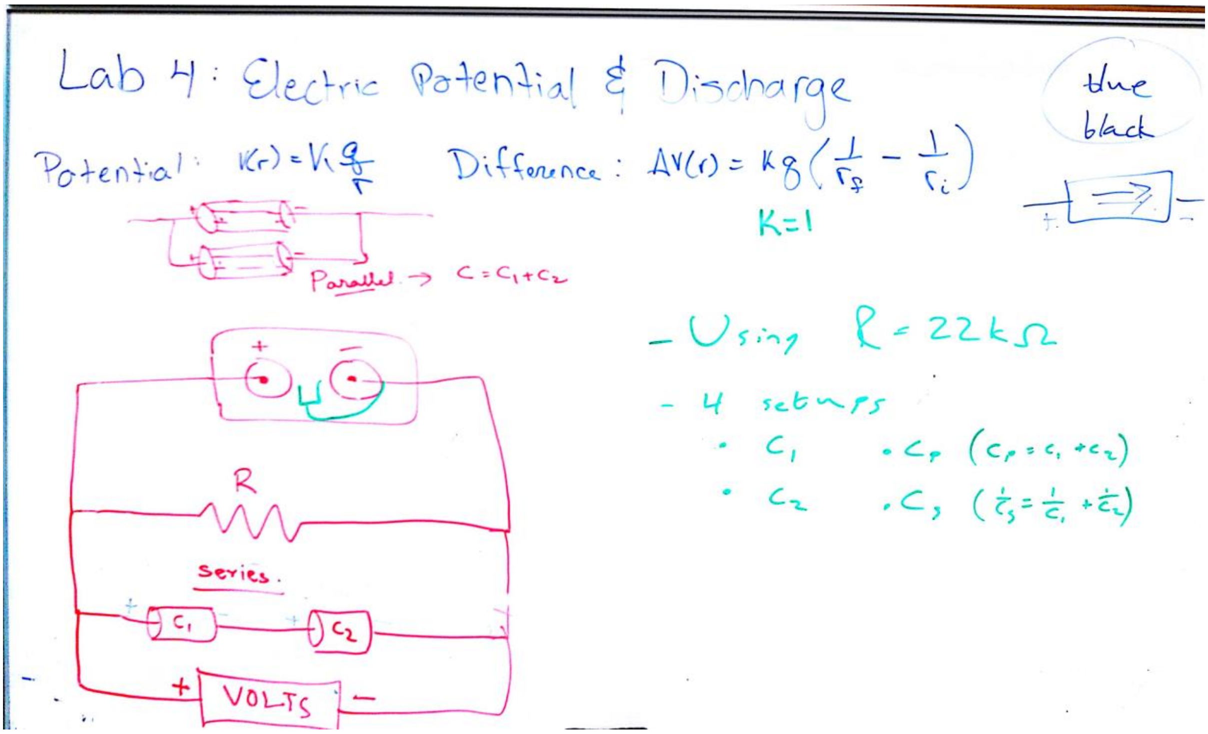
8. Using a single point charge of –2, indicate where (how many grid units away) you would place initial and final points in order to have a potential difference of –3 V. [Note: $\Delta V = -\left(\frac{U_b}{q_0} - \frac{U_a}{q_0}\right) = q\left(\frac{1}{r_f} - \frac{1}{r_i}\right)$, begin at page p761and continue through p 770, 13th edition Young & Freedman and remember that k=1 for our purposes.]

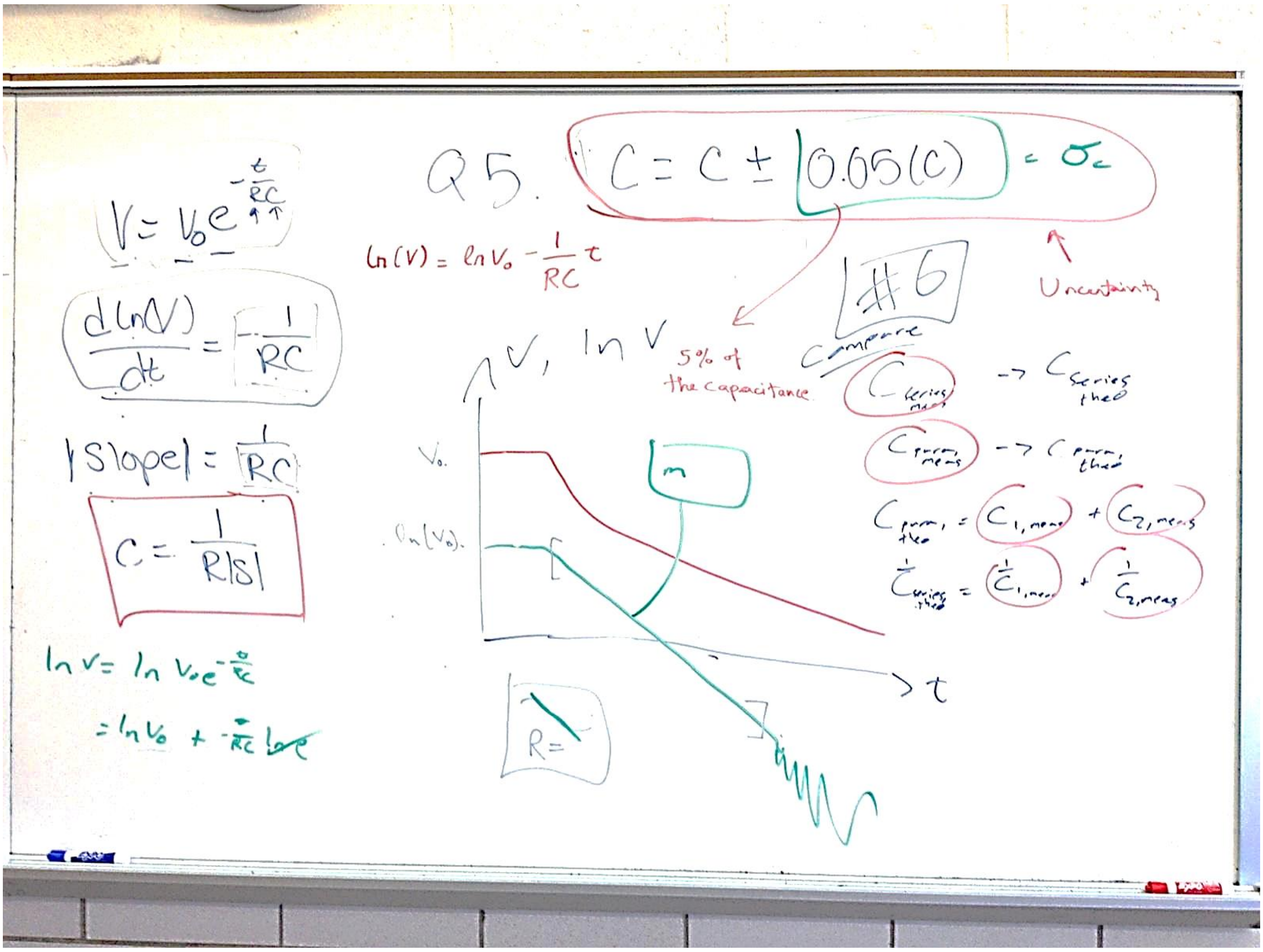
In addition, the worksheet tells students to report their results in an "industry standard form". However, this statement is misleading because there is no "industry standard" for reporting data. It is important for students to know how to report their results – but it is equally important not to mislead them into thinking that there is only one "correct" way to present the data.

In all, this lab operated smoothly – but only because the TAs did not give students a chance to make mistakes or complete the lab themselves. In order for students to learn and benefit from the lab sessions, it is critical that the TAs allow students to make their own observations and analyze their own data.



1A photograph of the circuit board that students are provided.





Q5.
C = C ± 0.05(C) = σc
Uncertainty
5% of the capacitance
#6
Compare
ln(V) = ln V0 − 1/RC t
V = V0 e^(−t/RC)
d(ln(V))/dt = −1/RC
|Slope| = 1/RC
C = 1/R|S|
ln V = ln V0 e^(−t/RC)
= ln V0 + −t/RC
V, ln V
V0
ln(V0)
m
R=
t
C series meas → C series theo
C para, meas → C para, theo
C para, theo = C1, meas + C2, meas
1/C series theo = 1/C1, meas + 1/C2, meas

5. Resistors and Light Bulbs

Procedure

Overview

In this experiment you will perform a set of experiments with two carbon resistors, which are good examples of linear resistors, and then you will perform an experiment with a light bulb, a good example of a nonlinear resistor. With the carbon resistors, you will measure the resistance plus uncertainty of each of two individual resistors. Then you will compare calculated and measured values of series and parallel combinations of the two individual resistors. With the light bulb, you will measure the changing resistance value over a range of applied voltage values.

Part 1:

In Part 1, you will be measuring the resistance of two different carbon resistors plus two combinations of those resistors: a series and a parallel combination. You will be measuring resistances just as you did in a previous Experiment, where you found that one careful set of measurements of potential versus current values gave a highly precise determination of resistance together with a measure of the resistance uncertainty.

Hook up a circuit in a similar manner to what you have done for measuring the resistance of one of the 51Ω carbon resistors on the Vernier circuit board. Once you are certain that your circuit is properly hooked up, check that the voltage-adjust knob on the power supply is turned fully CCW and then turn the power supply ON. Open the Ohm'sLawSP template, and then zero the reading. When the "Zero Sensor Calibrations" box opens, click OK, and then collect data.

Record nine datum points starting from 0,0 and then increasing the voltage setting successively from 0 to 4V by approximately 0.5V increments. After turning the voltage-adjust knob to the next desired voltage level, wait a couple of seconds to let the system settle down to its new current-voltage state before clicking the "Keep" button. When you have collected a total of nine V vs. I points, stop data collection. **Be sure to turn the voltage-adjust knob fully CCW to the zero position at this point.**

Perform a least-squares fit for your 9 datum points. Open "Linear Fit Options" from the right-click menu, and then select the "5-significant figures" and the "Show Uncertainties". Record (on your Worksheet) the slope and uncertainty of the straight-line fit to your 9 points with all digits, just as they appear in the data box – for the time being you will keep all digits for subsequent calculations. If you did everything properly, you should find that the slope-value (the resistance of the carbon resistor) has an uncertainty of only about 0.2% or less! (In the aggregate, these resistors are only specified to a 5% range above and below the nominal value of each resistor printed on the circuit board.)

Move the clip leads from the connection posts of the 51Ω resistor to those of one of the 68Ω resistors. Click the "Data" choice up on the main menu bar, and select the "Clear All Data" choice at the very bottom of the list that appears. Do NOT close the least squares data box that then becomes empty. Repeat the steps above involved in recording 9 datum point with which you will determine the resistance and uncertainty of that resistor, and record resistance and uncertainty on your Data Sheet, again writing down all available digits. Once complete, repeat with the resistors arranges in series and then in parallel configurations. We will refer to these four resistance values, in order, as R_1, R_2, R_s, and R_p.

Part 2:

As you have seen, the carbon resistor is AMAZINGLY linear (constant resistance value independent of the voltage). So are ALL resistors of constant resistance value? Absolutely not! One of the best examples of a resistor that changes values with applied voltage is the light bulb – as the voltage increases, the temperature of the filament changes, thus causing the resistance to… well… It would be much better for you to find out for yourself how things change. And that is what Part 2 is all about.

There is a light bulb (labeled as #50 – a round-headed bulb, NOT a long-headed bulb) in one of the three sockets mounted on the circuit board. Make sure that the power supply adjustment knob is set to zero volts (fully CCW), and change the clip leads from the resistors to the light bulb binding posts so that you can use the same circuit as in Part 1 to make I-V measurements in Part 2. When you believe that everything is properly connected, run the voltage up to 3 V and back. If the current increases with voltage AND the light bulb begins to glow at the top voltage value, then all of your circuit connections are probably OK (at least if the polarity of the Current probe is correct).

Go through the zeroing procedure, just as before, and then collect and record datum points for voltages of 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.00V, and then by 0.25V increments up to a maximum of 4.0V. (These voltages need only be adjusted APPROXIMATELY to the above values. **Also, you should wait several seconds after adjusting the voltage to record the datum point in order to let the system settle down to each new current/voltage situation.**) And as you are recording all these datum points as the voltage increases, please note the voltage level at which the bulb first begins to glow, and record that value on your Data Sheet.

Once you have finished recording all of the datum points, click “Stop,” and then click the <u>tangent function</u>. Move the cursor horizontally to move the tangent line from one datum point to another. At each point the data box will give the slope of the tangent line (the resistance) at that point. Here are some conditions to evaluate: determine the voltage corresponding to the minimum and maximum resistance, and record these resistances; determine where the resistance value is changing most rapidly and record that information, also. For these three conditions remember to write down the resistance vales in <u>Standard Form</u>. (Hint! Consider using the Linear Fit Function.)

Now you have seen two wildly different examples of resistors – the extremely linear carbon resistor and the extremely nonlinear light bulb – and you have finished the data-collection portion of this experiment.

Worksheet

WPI Physics

PH 1120 -- Resistors & Light Bulbs -- Lab Report

Your Name: ? Partner’s Name: ?
Section: ? Date: ?

1. <u>Write down</u> the values for your measured R_1 and R_2 in standard form (Uncertainty to one digit unless the lead digit is 1, in which case the first two digits are retained; the main value is then written with digits to the same decimal place as the uncertainty. This may very well involve

more or fewer digits than the three we ask for on exams and summary homework – here it just depends on the precision of the particular experiment you are doing.).

2. The equivalent resistance of two resistors in series is given by $R_s = R_1 + R_2$. Because R_1 and R_2 are independent of one another (determined by independent sets of measurements), the best-value uncertainty of R_s is determined by the following method: square the individual uncertainties of R_1 and R_2, add the squares together, and take the square root of that sum (this is called the "quadrature" of those two numbers). Now you can write down the calculated R_s-value, complete with uncertainty, in industry-standard form. If you made the measurements in a reasonably careful and consistent fashion, you should find that the MEASURED and CALCULATED values of R_s, each complete with uncertainty, should OVERLAP (or NEARLY so, to within a factor of 2 times the individual resistance uncertainty – or less) in resistance values. Do they?!

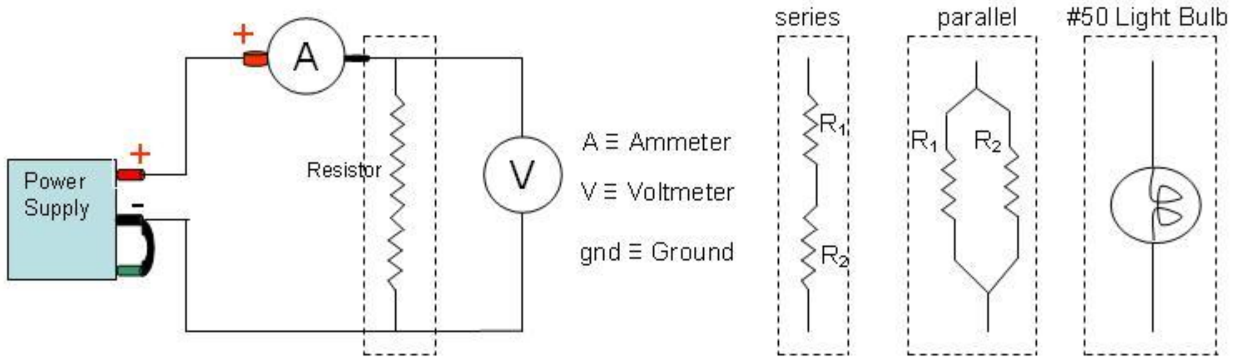
3. If they DO overlap (or nearly so), congratulate yourself on an experiment properly conducted! (If they don't come close to overlapping, please show your work to your lab instructor – something has evidently gone horribly wrong, and perhaps your lab instructor can spot the problem!) You have also learned some important information about precision of data (that is, how many digits to write down in conveying numerical information). The uncertainties determined for you by the least-squares fitting routine in this experiment ARE the precision of their corresponding slope values (in this experiment, the resistance values), and the industry-standard rules for presenting numerical results COMPLETE WITH UNCERTAINTIES prevent us from stating more digits than we are entitled to present. Because $R_p = (1/R_1 + 1/R_2)^{-1}$, the application of the proper rules is a bit more complicated than for R_s, and we are NOT going that far. So for this Lab Report you will simply be asked for the calculated value of R_p from measured values of R_1 and R_2. You just won't be asked to go through a determination of calculated uncertainty for the derived quantity R_p. (But you can still compare the measured with the calculated value. How do they compare? How might you express this comparison? How about in terms of percentage deviation, one from the other?) Calculate R_p and the percentage deviation between the calculated and measured values.

4. State the voltage at which the light bulb first begins to glow.

5. State the minimum and maximum resistance (in standard form) measured for the light bulb in the range 0 to 4 V. Also state the R-value (in standard form) you found in the range where the resistance was changing most rapidly. (The ONLY reason for stating the uncertainties here is to convey an indication of the precision of your resistance measurements, which of course depends on how many measurements you made and how close together they are.)

Our Analysis of this Laboratory

The Resistor and Light Bulb Experiment serves to familiarize students with the behaviors of both linear and nonlinear resistors. To complete this experiment, students are provided with an assortment of resistors – a 58 ohm resistor, a 68 ohm resistor, and a light bulb. With these resistors, students are asked to construct a simple circuit (similar to the one created in Lab 3) and measure the values of the resistors in both series and parallel arrangements.



2- The circuit diagram for this lab

The most evident problem with this lab is that the conclusions of Part I and Part II are provided for students within the instructions. Ideally, students should be making these observations themselves. The beginning of Part II states, “As you have seen, the carbon resistor is AMAZINGLY linear (constant resistance value independent of the voltage).So are ALL resistors of constant resistance value? Absolutely not!” Additionally, the end of the instructions state, “Now you have seen two wildly different examples of resistors – the extremely linear carbon resistor and the extremely nonlinear light bulb – and you have finished the data-collection portion of this experiment”. This problem persists within the worksheet questions as well. In question 2 of the worksheet is the statement, “If you made the measurements in a reasonably careful and consistent fashion, you should find that the MEASURED and CALCULATED values of R_s, each complete with uncertainty, should OVERLAP (or NEARLY so, to within a factor of 2 times the individual resistance uncertainty – or less) in resistance values. Do they?!” Explicitly providing this information not only defeats the purpose of the experiment, but it also removes the opportunity for students to practice developing and testing a hypothesis. Furthermore, there is no purpose for students to collect this data if they are not required to analyze it themselves.

Additionally, there are some issues with the procedure. In order to collect data, students are told to incrementally increase the voltage of the power supply and collect current vs voltage measurements within logger pro. In order to calculate the resistances, the instructions tell students to use the “tangent function” within logger pro. When using this tool, Logger Pro shows a (tangent) slope line at each point. Students are told to record this resistance value. Although the tangent function is a useful feature of logger pro, it should be avoided since it extrapolates data on either side of the point in order to generate a tangent line. Not only are students not warned about this behavior, but the only documentation that students are provided about this function is irrelevant. In the instructions, the words “tangent function” link to an almost completely blank page except for the text,

> “Now move the cursor into the x vs. t field, left-click the mouse there to select it, and then left-click the “M=” button up on the tool bar in order to obtain a slope-measuring tangent line on the x vs. t graph. Move the cursor around in the x vs. t field and note that the slope-value at a point on the x vs. t graph is identical to the corresponding v_x-value on the graph below (as it should be, of course!).”

This information refers to the instructions of an 1110 lab and are completely disconnected from this experiment.

Another issue with this lab is the lack of professionalism within the instructions. For instance, in question 3 of the worksheet, students are told that if their measured and calculated values of the resistors in series do not overlap, then “please show your work to your lab instructor – something has evidently gone horribly wrong”. This tone is carried throughout most of the lab instructions and should be revised to be more formal and less disparaging.

Moreover, this lab does not include any problem-solving suggestions within the instructions. Because this is most students’ third time working with circuits, many are still unfamiliar with following circuit diagrams and constructing the required circuits. It would help tremendously to include a few short sentences on how to confirm that everything has been set up correctly. This way, students do not need to rely on the TAs to verify correctness, and therefore, the TAs will be able to spend a greater amount of the lab time helping students with other areas of the lab.

Finally, this lab’s instructions, like other PH-1120 and PH-1121 lab instructions, directs students to report findings in an “industry-standard” format. Students should be made aware that there is no such “industry-standard” when reporting results and that such a statement is vague and misleading.

6. Linear vs. Nonlinear Circuits & Magnetic Field Measurements

Procedure

Overview

In this experiment you will be conducting two quite different kinds of experiments. First you will be making current-voltage measurements on two similar series-parallel resistive circuits. The only substantial difference between the two circuits is that one will contain only carbon resistors (LINEAR resistive elements) and the other will have a light bulb (a NONLINEAR resistive element) substituted for one of the carbon resistors. This experiment will give you practice in figuring out current and voltage values in this series-parallel circuit, even when not measured directly, as well as acquainting you with the substantial difference between linear and nonlinear behavior.

Second you will be making magnetic field measurements using a special device called a Hall Effect probe, named that way because it uses the "Hall Effect" to make its magnetic field measurements. All that you need to know about the Hall Effect probe is that it contains a thin, flat wafer of a semiconductor material and is sensitive to the DIRECTION of the magnetic field as well as its MAGNITUDE. The wafer is mounted about 1 cm back from the tip of the probe with its SURFACE-NORMAL parallel to the long axis of the probe. This results in the probe reading the greatest magnetic field strength (magnitude) when the magnetic field is parallel (or anti-parallel) with the long axis of the probe. This further means that the probe measures zero field strength when the magnetic field direction is PERPENDICULAR to the long axis of the probe.

Part 1:

In the first part of this experiment you are going to hook up a somewhat complicated series-parallel circuit made up of carbon resistors.

Hook up the resistor circuit (as shown in the Circuit Diagram and discussed by your lab instructor) involving three carbon resistors of labeled values of 10, 51, and 68Ω. Please note that you are to include as part of the circuit a pair of current sensors for measuring electrical currents through two different parts of the circuit AND a pair of voltage sensors for measuring the electrical potential difference across two different parts of the circuit. With these current and voltage measurements, you will be able to determine the voltage across and current through each of the three resistors.

Open up the Kirchhoff template, turn the voltage-adjust knob of the power supply fully CCW to the zero position, and then turn the power supply ON. Zero the reading and begin collecting data. Use the Keep function to collect data from 0 V to 5 V in 1V increments.

Perform a least-squares fit on the upper grapher. Right click on the data box that opens up, select the "Linear Fit Options," and then select 5 significant figures and the "Show Uncertainty" choices. Record your results on the Worksheet. Once finished with the top graph, do the same with the lower graph, and record those results. Note that your result for the I_1,V_1 data set is the equivalent resistance of this parallel/series circuit, and the result for the I_2,V_2 data set is the actual measured resistance of the 68 Ω resistor. Note how well the datum points on each graph fit a straight line. Because the carbon resistors are so linear, **ALL** of the currents and voltages increase linearly as the voltage across the circuit is increased.

As you bring the cursor close to the upper-right datum point, it will become a small circle which can be accurately centered on the datum point. This will allow you to read the I,V values of that point, appearing at the lower left corner of the graph. Record those values on your Data

Sheet. Then repeat that process for the upper right datum point on the lower graph.

With those two pairs of I,V values, you will be able to calculate the resistance of each of the three resistors used in the circuit. To do this, go to the Circuit Diagram and next to each resistor in the sketch, write down the respective voltage across it and the current through it. (Some of these values you have measured directly. The values not measured you can deduce from the set of measured values. For example, the voltage across the 51 Ω resistor is your measured V_2 value, and the current through the 68 Ω resistor is your measured A_2value. And please be aware that the voltage across the 10 Ω resistor is NOT equal to the voltage across the entire circuit!) Given the numbers in this sketch, you will be able to calculate the resistance value of each resistor using Ohm's law.

Make sure the voltage is down to 0 V and replace the 68Ω carbon resistor with the #50 light bulb already placed in one of the light sockets (Circuit Diagram 2). Test that all the probes are reading correctly by turning up the voltage to about 4 V and back down to 0 V (each probe should read a non-zero value as you do this and the bulb should light up). Zero the readings and take data as you did before. Notice how the presence of the light bulb changes the shape of the data.

After you've stopped the collection process, turn the voltage supply control knob fully CCW to the 0V position. In the same manner as in Part 1, record the I,V values for the far upper right datum point on each graph, and do the same for the first non-zero datum point on each graph closest to the 0,0 point. On your Lab Report you will be asked to figure out the current through and voltage across each of the 3 resistive elements at both the high- and low-voltage points so that you can calculate a resistance for each element at both the high and low points in your data set in order to demonstrate the nonlinear behavior caused by the light bulb.

Part 2:

Now you will use Vernier equipment to measure values of actual magnetic fields, such as those created by permanent bar magnets.

Open the MagField1.cmbl template. Set the range switch on the magnetic field probe to the 6.4 mT setting. With the magnetic field probe held in place on the surface of the lab bench, zero the reading, and then begin collecting data. Keeping the magnetic field probe motionless on the bench top, slide the bar magnet along the table top toward the probe along an extension of the long axis of the probe. Watch the probe meter reading, and **be careful NOT to exceed a magnetic field magnitude of 5 mT** (which is just below the upper-reading limit of the magnetic field probe). Move the bar magnet some distance away, turn it end-for-end, and slide it in directly toward the probe again. When at a reading of approximately 5 mT magnitude, don't bring the magnet any closer but rotate it around its center slowly while watching the magnetic field reading carefully. Rotate through at least 360°.

Now move the magnet far away from the probe, and this time slide it in along a line perpendicular to the probe and aimed at a point about 1 cm back from the probe tip. As you push the magnet closer, adjust the distance of its line of travel either closer or further from the tip in order to make the probe reading close to zero. Because the magnetic field lines diverge from one another after leaving the tip of the bar magnet, the magnetic field in the vicinity of the Hall Effect wafer (inside the probe) will have a small component along the axis of the probe unless the center of the bar magnet is aimed exactly at the wafer, and by slight adjustment of the bar magnet's line of travel, you can aim the center of the bar magnet end directly at the (hidden) wafer, so that the measured field strength is zero.

At this point you have established that the probe is most sensitive to fields parallel (or antiparallel) to the probe's long axis and oblivious to fields that are perpendicular to the long axis of the probe. (Actually, this field sensitivity varies as the cosine of the angular difference between the probe axis and the direction of the magnetic field at the wafer.)

Take a paper clip and bring it up to the tip of the probe. Turn the paper clip end-for-end, and determine from this test that the paper clip is not magnetized. If it does cause a small reading as you turn it end-for-end, throw the paper clip vigorously to the floor or against the wall a few times, and that should remove most of any residual magnetism. (Related admonition: Do NOT drop the permanent magnets on the floor or on the lab bench. With abuse, even a permanent magnet can lose a bit of its magnetization.)

Now move the bar magnet to a point some distance away from the probe, and place a paper clip near one end of the bar magnet (near enough that the clip leaps to that near end of the magnet). Because the paper clip is made of a magnetic material (soft iron), the paper clip is attracted to the magnet and can be made to cling to one end. Holding the paper clip so that it touches the magnet and sticks straight out along the long axis of the magnet, slide this arrangement toward the probe along the probe's long axis with the paper clip between the magnet and probe. As the clip+magnet arrangement approaches the probe, a nonzero field value should begin to register, and as long as the reading never exceeds 5 mT, you can bring the free end of the paper clip right up the flat end of the probe. With the paper clip held firmly in place against the probe, take the magnet out of contact with the paper clip, bring the magnet back again, and repeat this cycle several times while watching the probe reading. Reverse the direction of the bar magnet, place the paper clip against the end of the magnet pointing toward the probe, and slide the clip+magnet arrangement in toward the probe as before. Repeat as above for this new situation.

With the clip+magnet touching the end of the probe, leave the magnet in place, and this time remove the paper clip. Reinsert and remove the paper clip through a few cycles, noting the behavior of the probe reading as you do that. Then place the paper clip on the other end of the magnet, reverse the direction of the clip+magnet arrangement, and again remove and reinsert the paper clip through a few cycles.

Take away the magnet and place it at some distance. Place the paper clip against the probe tip and observe the probe-reading change as you rotate the clip end-for-end. You should observe that the paper clip retains some residual magnetization, and you will be asked to describe your observations on your Lab Report. Now throw the paper clip down on the floor at least two or three times and repeat the end-for-end measurements as above. What do you observe now?

Here's the point. In all magnetic materials there are lots of little magnetic domains where all atoms in a given domain have their microscopic magnetic moments – their tiny bar magnet equivalents – all lined up in the same direction. In a permanent magnet, all these little domains can be more or less lined up, giving a large resulting magnetic field, AND these domains tend to stay lined up for a LONG time unless the temperature of the magnet is raised to a high-enough level to cause the domains to disalign OR unless the "permanent" magnet suffers enough dropped-to-the-floor type abuse. We call such material a "hard" magnetic material (a "hard" magnetic material requires a LOT of abuse to lose any of its magnetism, but we don't want our magnets to lose even 1% – so treat them CAREFULLY).A paper clip, of the other hand, is "soft". Although it has domains containing atoms that tend to be all magnetized in the same direction, these domains only line up cooperatively when an external magnetic field is applied, and this alignment largely disappears when the field is removed. But "largely" does not mean "completely". You'll no doubt be interested to learn that any residual alignment of domains in soft iron (like a paper clip) can usually be completely disrupted by a few sharp impacts (like throwing the paper clip to the floor a few times).

Worksheet

WPI Physics

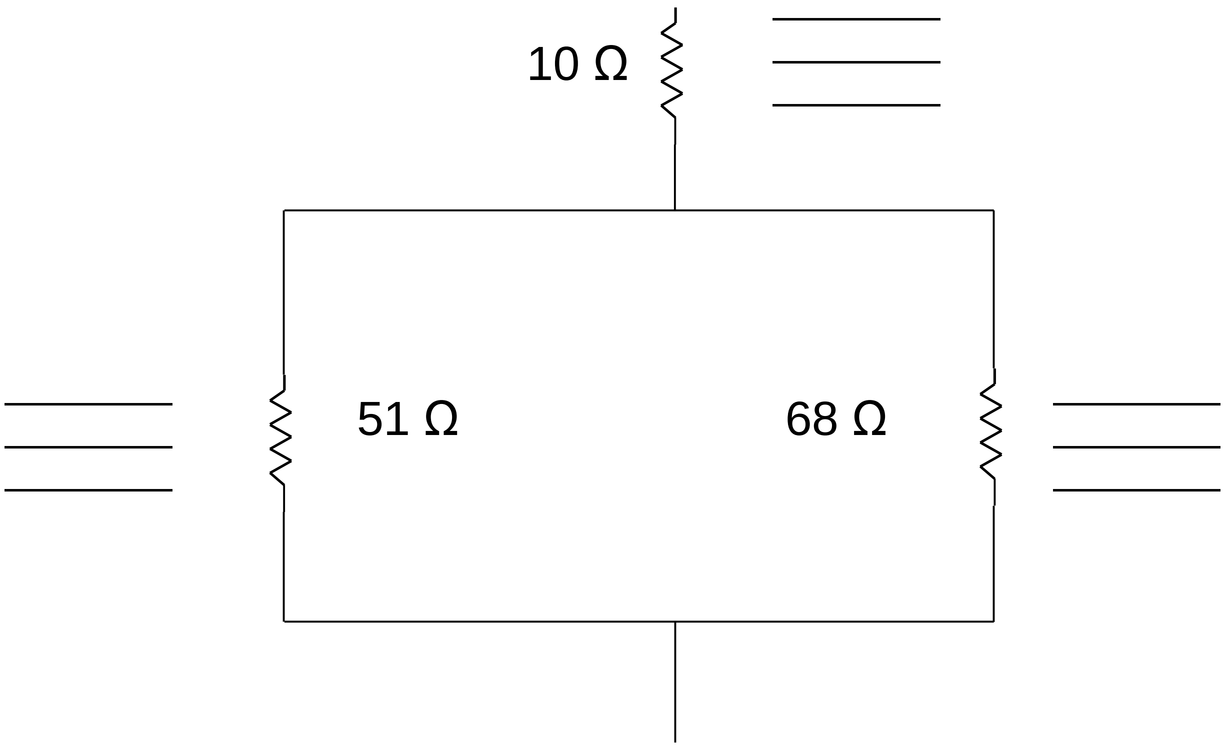
Linear vs Non-Linear Circuits; Magnetic Field Measurements Lab Report

Your Name: ? Partner's Name: ?
Section: ? Date: ?

1. Report your least-squares-fit values for both the equivalent circuit resistance and R_{68} in industry-standard form (uncertainty rounded to one digit, unless that digit is one, in which case round the uncertainty to two digits; the main value then rounded to the same place value as the uncertainty).

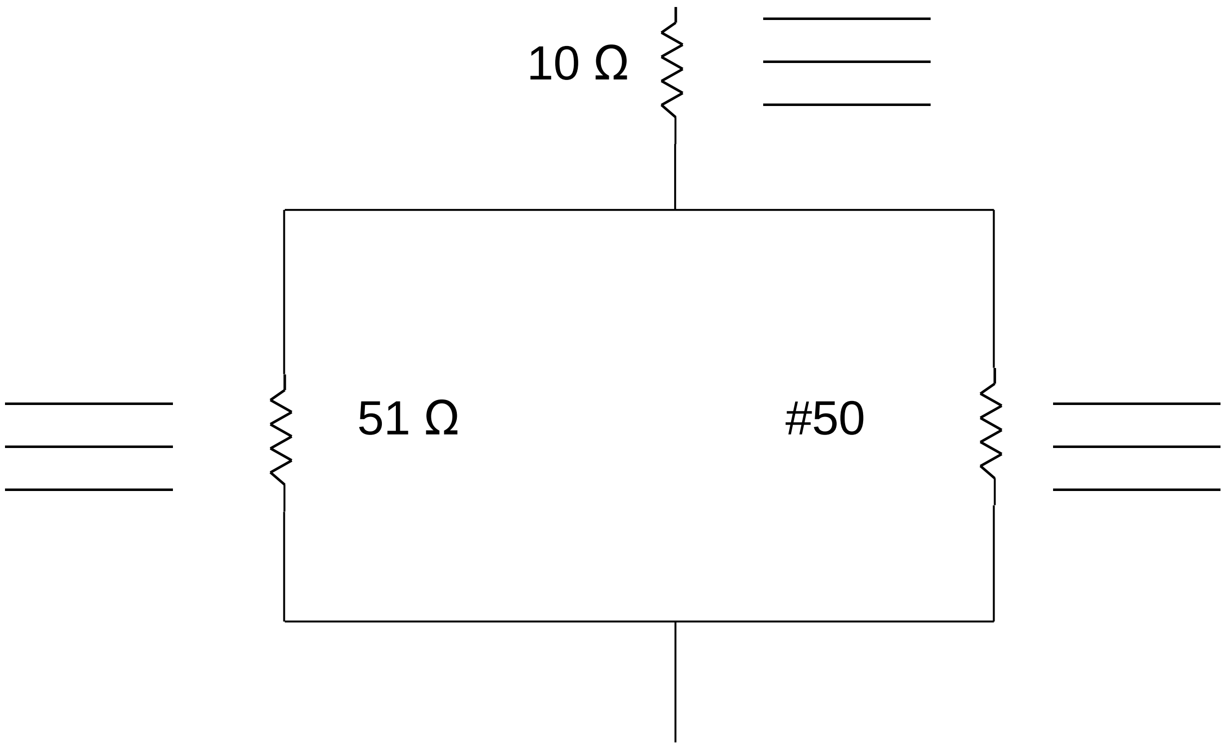
2. For the linear circuit, fill in the V, I, and R = V/I values for each of the three resistors in Sketch #1 where indicated. With the original two pairs of I,V values, you will be able to fill in the I,V values for each of the three resistors. Then you will be able to calculate the resistance of each of the three resistors used in the circuit from the corresponding I,V data using Ohm's law. (Some of these I,V values you have measured directly. The values not measured you can deduce from the set of measured values. For example, the voltage across the 51 Ω resistor is your measured V_2 value, and the current through the 68 Ω resistor is your measured A_2 value. And please be aware that the voltage across the 10 Ω resistor is NOT equal to the voltage across the entire circuit! Rather, it is the difference $V_1 - V_2$.)

Sketch #1

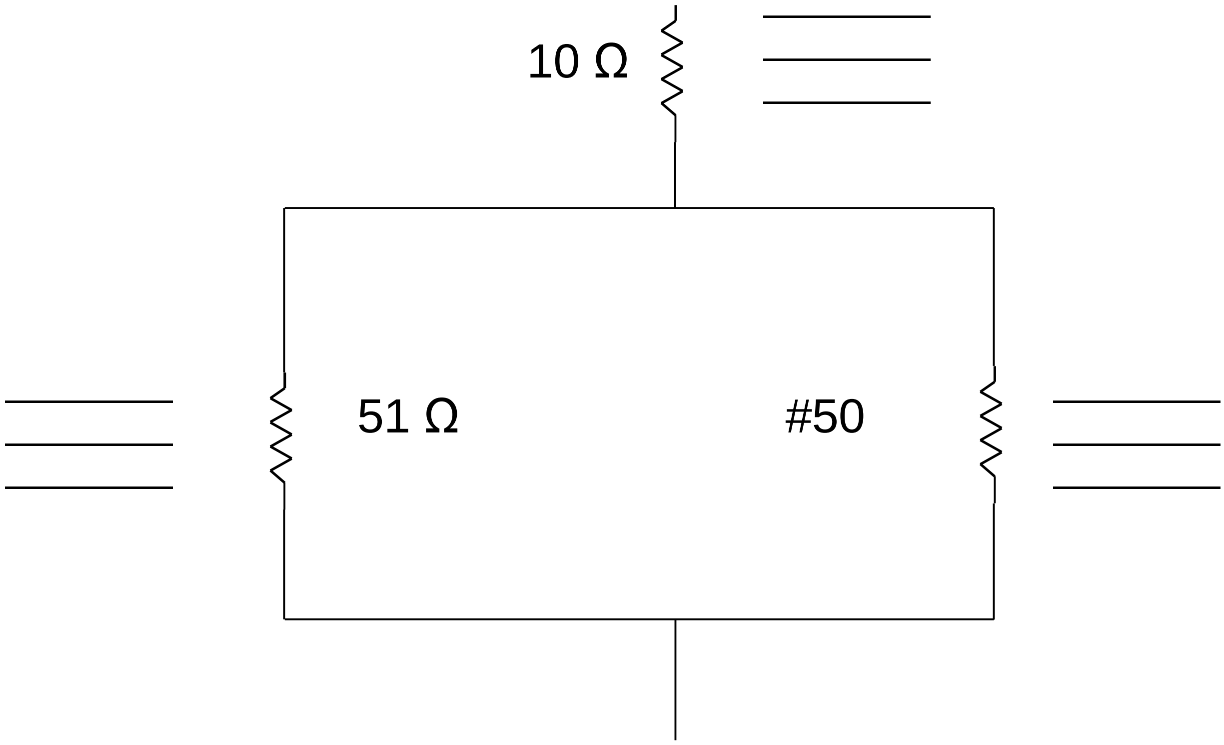


3. For the nonlinear circuit, fill in the V, I, and R = V/I values for each of the three resistive elements in Sketch #2 for the maximum-V point, and in Sketch #3 for the minimum-nonzero-V point. Just as above in Problem 2, place the actually-measured values where appropriate, and then figure out the remaining I and V values using standard circuit analysis techniques. Determine the R values from the corresponding ratios V/I (recognizing that Ohm's law does not work properly for nonlinear elements – the slope of the tangent line would be better – but comparisons of the V/I ratios at the two voltage extremes will demonstrate the nonlinear behavior well enough).

Sketch #2



Sketch #3



4. Record the peaks of the three orientations of the paperclip:

   In-line with the probe and magnet: ______________

   Perpendicular to the probe and magnet: ______________

   Diagonal to the probe and magnet: ______________

   Discuss these results.

5. Explain briefly what must be going on with the magnetic field measurement when the magnet is in a fixed location relative to the Hall Effect probe and a paper clip is slipped in between the magnet and probe (touching both at either end) and then removed. In other words, explain briefly your view of why the probe reading changes as the paper clip is slipped in and out.

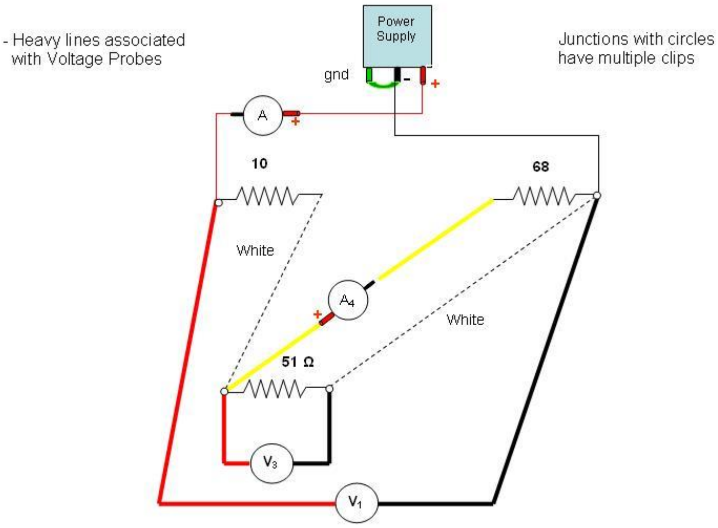
6. Explain briefly what must be going on with the paper clip when it registers a magnetic field with the probe when the bar magnet is first taken away, but then shows very little magnetic field after being thrown vigorously to the floor a few times.

Our Analysis of this Laboratory

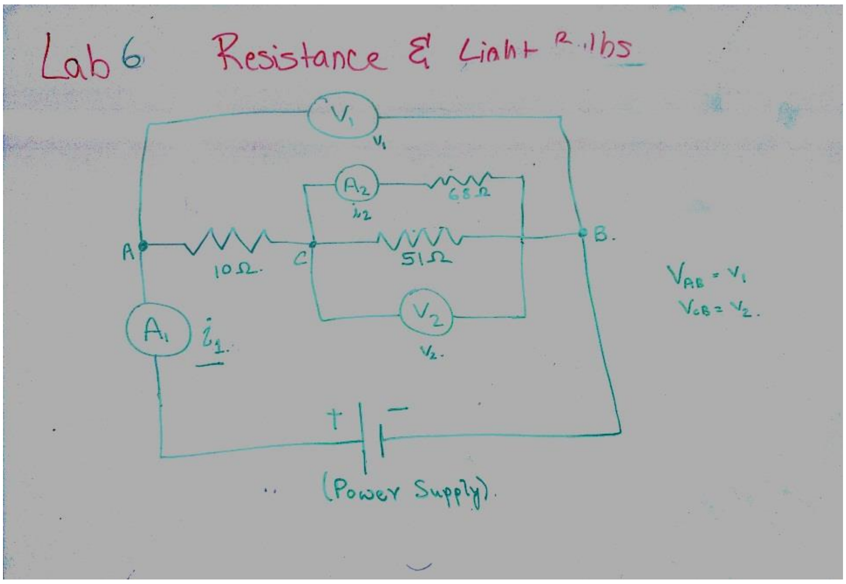
The Linear vs. Non Linear Circuit & Magnetic Field Measurements laboratory contains two different experiments. The first experiment attempts to further familiarize students with circuit diagrams, reinforce the students' knowledge about nonlinear and linear resistors, and teach students how to calculate current, voltage, and resistance across a variety of linear and non-linear resistors. The second experiment within this lab requires students to use a hall-effect probe to study magnetic fields. While both of these experiments are worthwhile, there were a variety of problems with the lab instructions and way that the TAs managed the lab.

Students spent the majority of the available lab time constructing the circuit that is used in the first experiment. Compared to the circuits in previous labs, this circuit was much more complicated to assemble. In most lab 6 sections, the students were instructed to verify with either the lead or assistant TA that the circuit was constructed properly. If the circuit was improperly setup, the TA typically made the necessary adjustments and instructed the students that they could begin collecting data. This not only destroyed the educational value of the lab (since many students did not get a chance to set up the circuit themselves), but many groups sat idly and wasted time as they waited for the TA to check their circuit. One section, however, took a much more educational and effective approach to this problem. Rather than having students check their circuits with the TA, the TA told students how to check the circuit themselves. He told students to open Logger Pro and verify that the ammeter and voltmeters were reporting appropriate, non-zero values. While the TA still answered student questions about the circuit, he interfered much less than other TAs and allowed the majority of students to construct the circuit by themselves. Even though there was no assistant TA present, students in this section, on average, had completed as much (if not more) than sections that used the normal procedure for checking the correctness of the circuit. This approach seemed to be much more effective and taught students valuable debugging skills.

Additionally, the difficulties that students experienced while attempting to build the circuit was only compounded by the messy circuit diagram that was included in the lab instructions. In order to alleviate this problem, the TAs sketched a much clearer diagram of the same circuit on the whiteboard at the front of the room.



The circuit diagram included in the instructions



The circuit diagram that was drawn on the board by the TAs

In one lab section in particular, two groups were unable to get the circuit properly constructed at all. After having spent over half an hour trying to get the circuit built, these groups asked the TA for assistance. The TA was also unable to get the circuit working and attributed the difficulties to malfunctioning sensor equipment. Because these groups were unable to collect any data for this portion of the experiment, the TA asked a group that had successfully collected data to email their findings to the groups that experienced problems. During the time that the TA spent helping these students, only the assistant TA was available to help answer questions from students. At the end of the lab, less than half of the class had fully finished conducting the experiment.

This lab instructions also suffered from problems with organization. The overview sections of the lab instructions, which is typically used to provide students a brief description of what the experiment entails, provided students with important details about the magnetic field portion of the lab. The overview reads,

> "All that you need to know about the Hall Effect probe is that it contains a thin, flat wafer of a semiconductor material and is sensitive to the DIRECTION of the magnetic field as well as its MAGNITUDE. The wafer is mounted about 1 cm back from the tip of the probe with its SURFACE-NORMAL parallel to the long axis of the probe. This results in the probe reading the greatest magnetic field strength (magnitude) when the magnetic field is parallel (or anti-parallel) with the long axis of the probe. This further means that the probe measures zero field strength when the magnetic field direction is PERPENDICULAR to the long axis of the probe"

These details are useful for students and should be moved to "Part II" of the lab instructions. They do not belong in the overview of the lab.

There are also a variety of issues with the clarity of the instructions. In Part II, students are instructed to "bring the magnet back again, and repeat this cycle several times while watching the probe reading. **Reverse the direction of the bar magnet, and repeat steps 6 and 7**." These instructions were especially confusing for students because there are no numbered steps present anywhere in the lab instructions. In addition, the instructions say, "With the magnetic field probe **held in place on the surface of the lab bench**, zero the reading, and then begin collecting data". The phrasing of this statement is misleading because students do not use anything to hold the probe in place. Finally, students were frequently mislead by the length of Part II's instructions, which spans multiple paragraphs. Despite its length, however, this portion of the lab only takes about ten minutes to complete. As a result, many students experienced difficulty managing their time within lab and rushed through Part I to get to Part II. In any section, only about a quarter of students seemed to be able to fully complete both parts of the lab. By revising these sections of the instructions, the clarity of the instructions could be greatly improved and students should be able to complete the lab in a much more timely manner.

It also became apparent that some student groups did not fully unwire their circuit before leaving the lab at the end of the allocated time. As a result, one group of students in the next section only needed to construct half of the circuit. The TAs should be very explicit in reminding students to completely unwire their circuits at the end of the lab section.

Finally, the worksheet tells students to "Report your least-squares fit values for both the equivalent circuit resistance and R[68] in industry-standard form (uncertainty rounded to one digit, unless that digit is one, in which case round the uncertainty to two digits; the main value then rounded to the same place value as the uncertainty). This statement is misleading – because *there is no* "industry-standard" for reporting results.

While this lab was effective in teaching students about magnetic fields and current and voltage values across a variety of resistors, the complexity of the instructions and the generally poor management of the lab by the TAs hindered its educational value. By splitting this lab into 2 labs, clarifying the lab instructions in the appropriate places, encouraging students to debug their own circuits, and teaching students how to manage their time throughout the lab, this experiment could be much more successful.

7. The Magnetic Field

Procedure

Overview

-

Today you will be measuring the magnetic field created by current flowing through a pair of 400-turn coils (which are very thick compared to a single-turn loop, but very short compared to most solenoids that are quite long compared to their inside diameter). With a modest-sized current flowing through these 400-turn coils, you will be able to measure a pronounced magnetic field, and learn a few things in the process.

Part 1

You are now going to use the Vernier equipment to measure the magnetic field created by a 0.40 A current flowing in a pair of 400-turn wire coils.

Hook up the coils to the power supply and current meter as instructed by your Lab Instructor. Before turning on your power supply, turn the Current Adjust • fully CCW and the Voltage Adjust • a couple of turns in the CW direction. If you are using a Pasco supply, it's labeled Current Limit Adjust, • and you should also put the meter switch in the Amps • position at the start. If you are using an H-P supply, depress the Range • button to the 2 A • position.

Set the magnetic field probe to the 6.4 mT sensitivity, and open the FieldCurrent.cmbl template. Then turn on the power supply, and zero the Vernier probes. Slowly turn "Current Adjust" CW until the Vernier current probe reads 0.40 A. If the current meter on the supply does not read approximately 0.40 A, please have your Lab Instructor look at your set-up.

Place the two coils beside one another so that their bores are aligned, and the coils separated by a few millimeters. Begin a 60 second data collection, and slowly insert the magnetic field probe in one end of the bore and slide the probe through until it emerges from the second coil while watching the magnetic field graph that is being recorded in real time. (Be sure that the probe reading does not exceed the 6.4 mT level at any time.)

If the coils are creating fields in the same direction, you should see the magnetic field rise to a maximum value as the probe passes through the first coil, decrease to a relative low point when the field-sensitive region is halfway between the two coils, and increase again as the probe is slid through the middle of the second coil. If the coils are creating oppositely directed fields, the field strength at the halfway point should go through zero and then reverse polarity as you slide the probe through the second coil.

Regardless of which arrangement you start with, slide the probe through the pair of coils at least a couple of times while recording the field and current readings. Then turn the current down to zero, reverse the wire connections to just one of the coils, thus reversing its polarity, turn the current back up to 0.40 A, and slide the magnetic field probe through both magnets another couple of times, again while recording the field and current readings.

Now slide the second coil away from the first coil (so that it does not contribute much to the reading of the probe when the probe is in Coil 1). Zero the probes again, then slide the probe slowly through the center of the first coil while recording data so that you can obtain a good reading of the maximum field and corresponding current, which you then should record on your data sheet. Turn down the current to 0.30 A and repeat the above procedure, again recording results on your data sheet. Repeat a third and fourth time for currents of 0.20 A and 0.10 A.

Worksheet

PH 1120 - The Magnetic Field - Lab Report
Your Name: ? Partner's Name: ?
Section: ? Date: ?

1. From the data on your Data Sheet, calculate the ratio of maximum magnetic field to corresponding current for each of the four pairs of values recorded. Does the maximum field value at least approximately scale in linear proportionality with the current?

2. For the coil used in your experiment, there were 400 windings in a span of 3.9 cm. Calculate the magnetic field you would expect to measure inside an infinitely-long solenoid of winding density 400 turns per 3.9 cm carrying a current equal to the greatest current value on you Data Sheet.

3. As an added calculation arising from Problem 2, calculate the percent deviation of your measured maximum magnetic field from that predicted by the ideal solenoid equation. (Because the coil you used is quite short, your measured maximum field should be about 80% of the solenoid prediction – maybe even a bit more than 80%. Is it?)

Our Analysis of this Laboratory

The Magnetic Field laboratory features a magnetic field probe that is inserted into a 400-turn coil, or solenoid, and reads the magnetic field created when a current is run through the coils. This reading is performed in two solenoids with their bores aligned. After the first reading the students turn the second solenoid around 180 degrees and perform the same reading. Next the students take away one solenoid and place it far away from the other so that it does not affect the magnetic field reading. Then the students perform a data collection on one solenoid while varying the current being run through the wire. While performing the experiments the students fill out a downloaded data sheet with their values for magnetic field. After the experiment is complete there is a worksheet to fill out.

Each lab is used to give the students a hands on lesson on a topic covered in class, this lab was on magnetic field. Why then is there a short magnetic field experiment in the Lab 6 section when Lab 6 covers linear vs. nonlinear circuits? That magnetic field experiment makes much more sense in this lab since Lab 6 took the students a long time to complete and most groups didn't even get to the magnetic field experiment during lab time. On the contrary this lab took the student much less time to complete. The first group finished the experiment after 20 minutes and every group finished before lab time was up. The magnetic field experiment from Lab 6 fits into Lab 7 much better. Alec and I both thought the experiment performed on this lab was effective. The equipment worked without any bugs. We thought that seeing the change in magnetic field as the students moved the probe was effective in demonstrating the behavior of magnetic field to the students. That being said the assessment of the student's knowledge of magnetic field was poor. The data sheet asks for the reading of max magnetic field for each current value used in the single solenoid experiment. This requires the students to look at a number on a graph and then type that number into a document. The worksheet has three questions the first is to compare those maximum field values. The second asks for a theoretical field value given the number of turns in the coil and the length of the solenoid. The students could measure the length themselves. An equation to solve for length is given to the students by the TA's. After the students find theoretical magnetic field, the last question is to find the standard deviation between the calculated and measured values. The students are never asked to assess the first experiment at all; they could have been asked a question on how the orientation of the field changes when one solenoid is turned 180 degrees. The students are not challenged at all by this lab; their knowledge of magnetic field is not tested. The only knowledge they are tested on is their ability to read numbers off a graph and ability to plug numbers into a few equations to come up with a solution.

Our suggestions for this lab would be to add the second experiment from Lab 6 into this lab. For time constraint issues it just makes more sense for that experiment to be in this lab. We also scrapping the data sheet and worksheet and writing new ones from scratch. This worksheet was simple; we think the worksheet should be a little more challenging and the data sheet can be omitted. The experiment in this lab was very good but we think the worksheet questions could have been made much better.

8. Electromagnetic Induction

Procedure

Overview

In the first part of this experiment, you will be making one more measurement of a magnetic field – the magnetic field of the Earth! The Earth's field strength is roughly 0.5 gauss, so if nothing else, this part of the experiment will give you practice in converting magnetic field units from tesla to gauss. Actually, we also hope that you will be intrigued by the manner in which the Hall effect probe can be used to scope out the DIRECTION of the magnetic field as well as its MAGNITUDE.

Then as a last part of this 8th and final experiment in PH 1120, you are going to make measurements that involve electromagnetic induction. We can't overemphasize the significance of electromagnetic induction. Given changes in the magnetic flux with time, you have already heard a lot about how to determine the polarity of induced EMFs in lecture. Part 2 will give you practice in predicting and observing the polarity of induced EMFs, and if understood properly should give you a good background for a sizable chunk of next week's Exam 4.

Part 1:

As you know, the Earth has a magnetic field, which is the subject of your magnetic field measurement for today.

Set the probe sensitivity switch on the magnetic field probe to 0.3 mT, open the MagField1.cmbl template, begin data collection, and move the probe around in space so that it points in all possible directions during one recording interval. Once the data collection process stops after 60 s, you will probably want to scale the graph. During data collection, note the probe orientation when the probe reading is at a maximum, and similarly note the orientation for the minimum reading. (The reason for the difference in readings is the Earth's magnetic field is directional, and the max and min readings should be found at probe orientations 180° apart.)

You may be surprised to find that the probe does not generally register the largest field strength in a horizontal orientation. Because the Earth itself creates a magnetic field similar to the field that would be produced by a large bar magnet buried way down at the center of the Earth, the field lines this far north of the equator have substantial vertical components (whereas field lines are pretty much parallel to the Earth's surface at the equator). ALSO, the building itself (because of a large amount of structural material made of iron) can distort field lines within the building, causing their directions to be noticeably different from textbook specification. Bottom line: the probe angle you observe for maximum magnetic field readings will have a vertical component, AND the angle may be somewhat different from one lab station to the next.

Orient the probe at 90° to the orientations of those extreme probe readings, zero the reading, and then start collecting data. During this recording, first sweep the probe's position around in the vicinity of the maximum reading (in order to get a good maximum value), and then reverse the probe direction by 180° and sweep through all possible nearby orientations (in order to get a good minimum value). The difference between max and min is twice the value of the Earth's field, and if you zeroed the probe at a good point, the max and min should be reasonably centered about zero. (It would be a good idea to determine whether your measured field strength is somewhere in the vicinity of 0.5 gauss. The Vernier probe is calibrated in tesla, the accepted unit standard for our customary system of units, BUT the Earth's field strength is such a tiny fraction of a tesla, you will usually find the Earth's field strength expressed in gauss, a unit of field strength that is 10^4 times smaller in size than the tesla.)

Part 2:

In this Part 2 you will be using a changing magnetic field (made by moving the bar magnet around) to induce an EMF (voltage) in a wire coil.

Setup:

- Unhook the magnet field probe from the LabPro Interface and replace it with the Differential Voltage probe. Connect the red and black leads of the voltage probe to the coil at your lab station, as described by your Lab Instructor. Place the blue foam circular pad on the bench, flat side up, and place the coil on that top flat surface with the central hole of the coil facing up. Open the Vernier template labeled "InducedEMF1.cmbl."
- Click the "Collect" button to start the voltage recording, and then slide the bar magnet at your station rapidly into the central hole of the wire coil. You should see a voltage spike appear on the recording. Now pull out the magnet rapidly. You should see another voltage spike, but this one with opposite polarity. (Why opposite?)
- Experiment with the speed with which you slide the magnet into and out of the coil. In general, the faster you slide the rod in or out, the bigger the induced EMF will be. As you slow down, however, you will reach a point where you will see NO effect from the changing magnet field – it's changing at just too slow a rate. Note that whenever the magnetic field is not changing (for example, if the magnet is still), there is no measurable EMF.
- Now turn over the magnet end-for-end, and repeat the previous two bullet-points, noting that the polarities of the voltage spikes are opposite from before. (Why?)
- Now pick up the coil, holding it in one hand with its hole horizontal. Pick up the magnet in your other hand, and move the magnet back and forth in the hole of the coil, MAKING SURE that that you can always see the color of the portion of the magnet inserted into the coil hole as you move the magnet smoothly back and forth (in other words, the magnet should never be inserted beyond its midpoint into the coil – otherwise, the polarity of the other half of the magnet will start to have an effect). This is one way to generate an alternating voltage (with which you could generate an alternating current) – by changing the magnet field periodically with time. An even more convenient way (used by your local electric power company) of doing this same thing is to rotate a coil in a constant magnetic field (as discussed in lecture!), making the angular orientation between a coil and magnetic field vary in a regular periodic manner. That's how an electric generator works!
- Now change the back-and-forth frequency from low to high (or vice versa), and note what happens to the amplitude of the resulting induced EMF. (Observe carefully because there will be a Worksheet question about the results of this variation of inducing an EMF.) To see the detailed shape of your induced EMF waveform, you might want to expand the time axis of your recording by clicking on and changing one or both of the extreme t-axis values.
- When you think that you pretty well understand the physics implicit in this part, you might increase the amplitude of magnet insertion into the coil so that both polarities of the magnet are having an effect inside the coil. If you can think of other ways of inducing and EMF in the coil with the magnet, short of causing some experimental component to crash to the floor, you are welcome to try those ways now.
- Now something new – a new learning opportunity!!! Put the coil back on the flat side of the blue foam pad, coil-hole vertical, and open the template InducedEMF2.cmbl (which only records for a 5-second time interval.

Procedure:

- Click on “Collect,” and before your 5 s are up, insert the magnet into and withdraw it from the hole in the coil, JUST ONCE, for one up-down pair of peaks in the induced EMF recording. Resize the graph as necessary to see a well-spread-out graph of that pair of peaks. It turns out that the areas under the two peaks should be the same, independent of the speed with which the magnet entered or exited the hole. To have Vernier calculate the areas, place the cursor to the left of the first peak (where the voltage begins deviating from zero), click and drag the cursor to the point where the graph of that first peak returns to zero, release, and then click on the “Area” button located between the “Stat” and “R=” buttons up on the tool bar. A box will open up giving you the area under that first peak. Then repeat those steps for the second peak. The area of that second peak should be opposite in sign but similar, if not identical, in magnitude to the area of the first peak. Record these areas for later use.
- Repeat this experiment, first inserting the magnet quickly, and then withdrawing it more slowly. Obtain and record the areas under each peak.
- As a final test, one partner should grab the coil in one hand, turn the blue foam pad over, making sure that it is centered on the black rubber sheet at your station, both placed well back from the edge of the bench (so that nothing ends up bouncing to the floor!), and hold the magnet vertically suspended with the other hand so that it can be dropped through the hole in the coil to land GENTLY in the slot of the blue foam piece. NOW THIS NEXT IS REALLY IMPORTANT! The coil should be held high enough above the blue piece so that the magnet does NOT bounce back up anywhere close to the coil, AND the magnet should be held initially at least an inch above the coil so that it starts out having no effect on the coil. When one partner has the coil and magnet all lined up, with the magnet ready to drop, the other partner (or the Lab Instructor, in the absence of a partner) should click “Collect.” When the recording starts, the magnet should be dropped, and if it drops cleanly through the hole to the foam piece underneath (and NOT bouncing to the floor!!!), that recording should provide good results. (If the drop wasn’t clean, simply try again.)
- In the manner described above, determine the area under both the positive and negative peak in your recording. Record these numbers for later use on your Worksheet, AND be sure to observe the relative durations of the two peaks (specifically, are they the same or does one peak have a larger duration than the other?).

Worksheet

WPI **Physics**

PH 1120 - Electromagnetic Induction - Lab Report

Your Name & Section: ?

Partner’s Name: ? Date: ?

1. State the value of the Earth’s magnetic field magnitude that you measured, and comment on the field orientation that you observed at your station.

2. Consider the magnetic induction situation when the magnet is rapidly inserted into a coil, held motionless, and then rapidly removed from the coil. Explain briefly the circumstances in this 3-step process that produce an induced EMF, and why their polarities are different.

3. Now compare the situation in Prob. 2 above with the identical situation with the magnet turned end-for-end. Compare the polarities of the induced EMFs in these two situations, and explain briefly the reasons behind the polarities observed (between the situations referred to in Problems 2 and 3).

4. Consider the situation where you moved the magnet back and forth in the coil in periodic fashion, thus inducing a periodic EMF in the coil. Specify the kind of periodic motion that led to the induced EMF of largest amplitude (rapid back-and-forth, or less rapid back-and-forth motion). Explain the physical reason for this observed behavior.

5. For the magnet withdrawal portion of this experiment, calculate the average of the three areas measured, and then calculate the maximum deviation of the area measurements from this average, expressing the deviation as a percentage of the average. Repeat these calculations for the three area measurements of the associated insertions of the magnet into the coil.

Our Analysis of this Laboratory

This lab serves to increase student understanding of magnetic fields. In the first part of the experiment, students use a magnetic field probe to measure the magnitude and direction of the Earth's magnetic field. In the second part of the experiment, students use a differential voltage probe to measure the changes in voltage as a magnet passes through a coil.

Students begin the lab experiment by using the magnetic field probe to calculate the magnitude and direction of the Earth's magnetic field. After collecting data, students are told to verify that their measured field strength is in the vicinity of 0.5 gauss. Ideally, this should be rephrased. Students should be told that the Earth's magnetic field is approximately 0.5 gauss, but it should be up to the students to determine what analysis is necessary for a properly conducted experiment.

Once students finish the first part of the experiment, they move onto part II, which tasks them with measuring the changes in voltage as a magnet is passed through a coil. These instructions tell students to “Place the blue foam circular pad on the bench, flat side up, and place the coil on that top flat surface with the central hole of the coil facing up.” This statement is hard to follow and should be revised for clarity. Something like, “Place the circular blue foam pad on the bench with the flat side facing up. Then, place the coil on top of the foam pad with the coil’s central hole facing upwards” is much clearer.

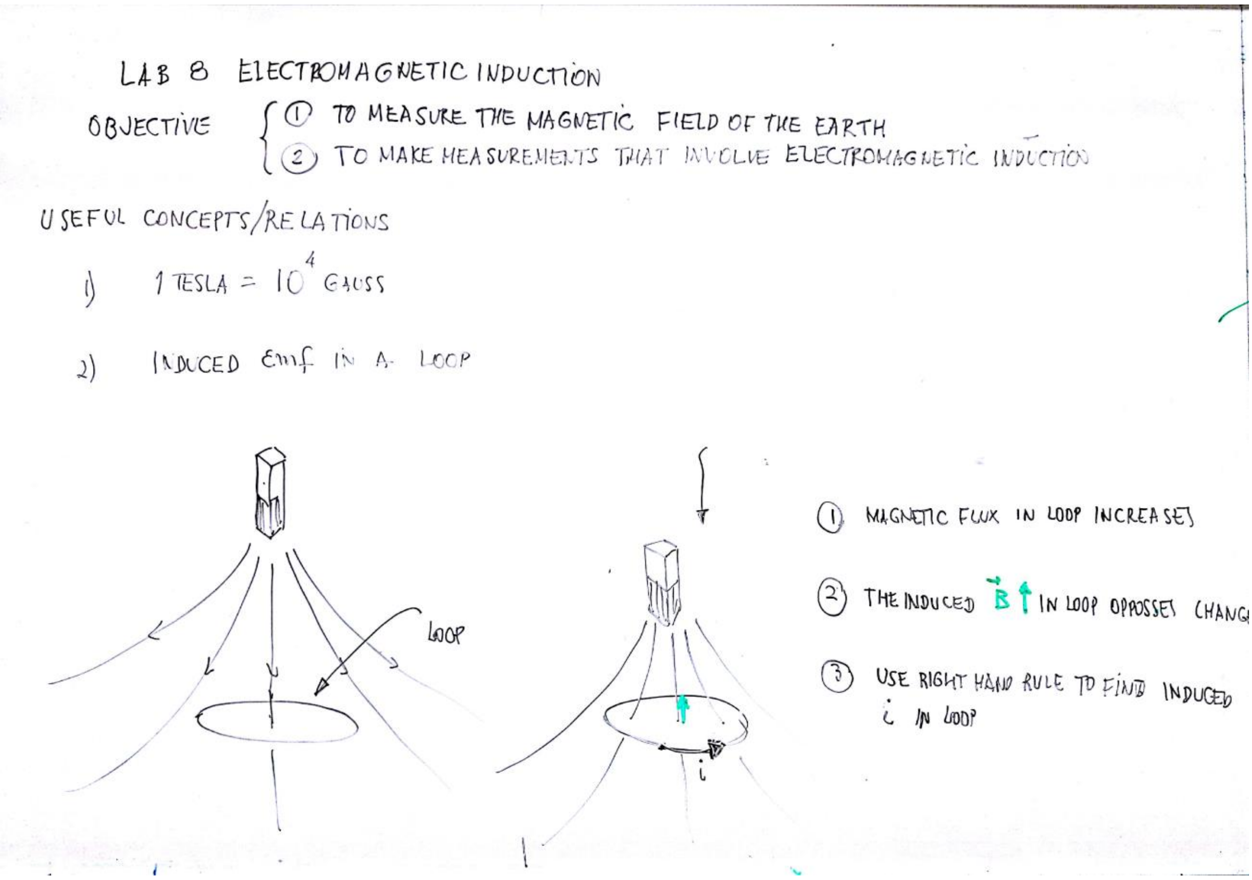
Later in the instructions for part II, the students are told to, “Click the ‘Collect’ button to start the voltage recording, and then slide the bar magnet at your station rapidly into the central hole of the wire coil. **You should see a voltage spike appear on the recording.”** This last sentence should be removed. Furthermore, the instructions say, “**In general, the faster you slide the rod in or out, the bigger the induced EMF will be. As you slow down, however, you will reach a point where you will see no effect from the changing magnetic field – It’s changing at just too slow a rate**”. The previous statements, this observation should be made by the students, rather than provided to students within the instructions.

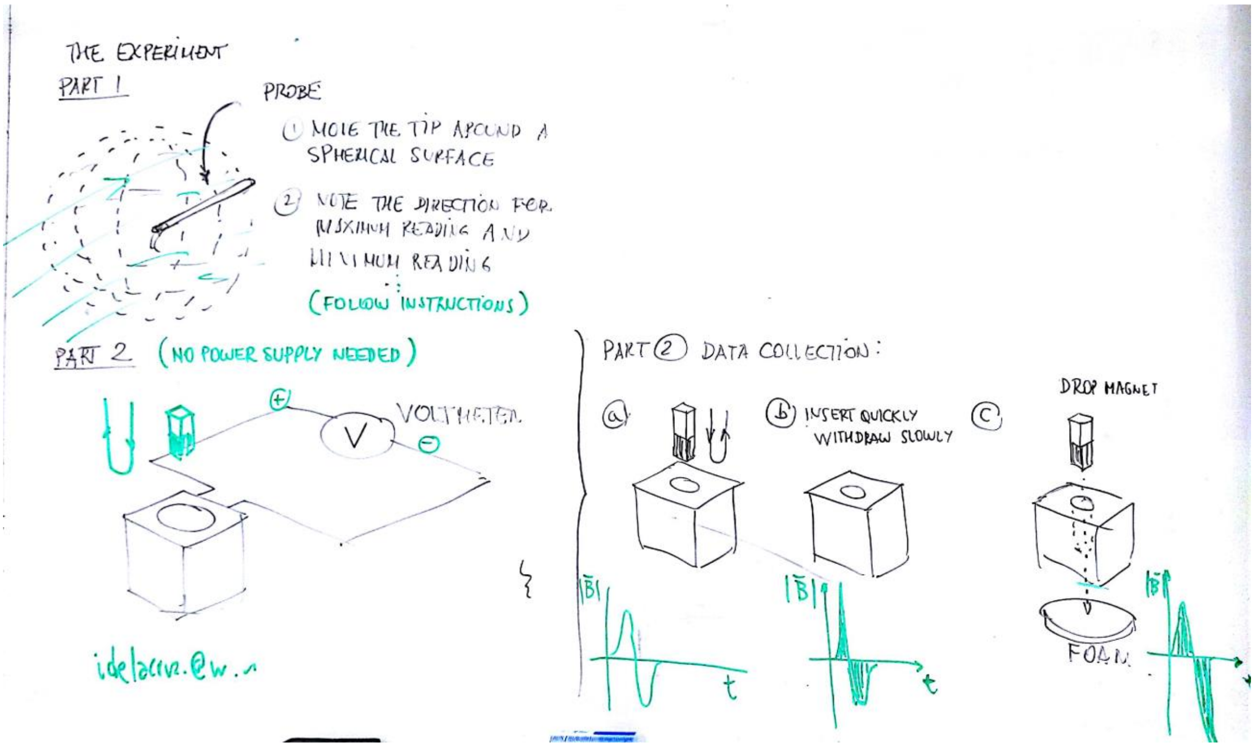
Next, it says, “Now turn over the magnet end for end, and repeat the previous two bullet points, **noting that the polarities of the voltage spikes are opposite from before. (Why?)**” Firstly, polarity is not the correct term to describe the appearance of the graph. Magnets have polarity, graph spikes do not. More importantly, students should be able to observe that flipping the magnet upside down will cause the voltage spikes to flip from positive to negative and negative to positive.

In the second half of part two, students are told to study the areas under the voltage peaks on their graphs. To do this, students are instructed to click on the “Area” button within logger pro. Logger pro will then automatically provide students with the area under the peak. It may be beneficial to explain to students that logger pro achieves this by taking the integral of the peak. Furthermore, the lab instructions tell students what their observations should be. The procedure states, “**The area of the second peak should be opposite in sight, but similar, if not identical in magnitude to the area of the first peak.”** Students should make this observation by themselves.

Finally, the instructions state, “As a final test, one partner should grab the coil in one hand, turn the blue foam pad over, making sure that it is centered on the black rubber sheet at your station”. Students are not provided with any rubber pad. The TAs made a note of this at the beginning of the section, but it would be best to remove this sentence from the procedure entirely to avoid confusion.

The most prominent issue with this lab is the amount of answers that the instructions provide students with. Because of this, students are given very little opportunity to make their own observations. Despite this, the worksheet questions are well put together. They ask students to analyze their findings and do a good job testing students’ conceptual understanding of the physics. This lab has the potential to be very educational – but its value is diminished by the poorly designed instructions.




THE EXPERIMENT
PART 1
PROBE
① MOVE THE TIP AROUND A SPHERICAL SURFACE
② NOTE THE DIRECTION FOR MAXIMUM READING AND MINIMUM READING
(FOLLOW INSTRUCTIONS)
PART 2 (NO POWER SUPPLY NEEDED)
VOLTMETER
V
PART ② DATA COLLECTION:
ⓐ
ⓑ INSERT QUICKLY WITHDRAW SLOWLY
ⓒ
DROP MAGNET
FOAM
|B|
t